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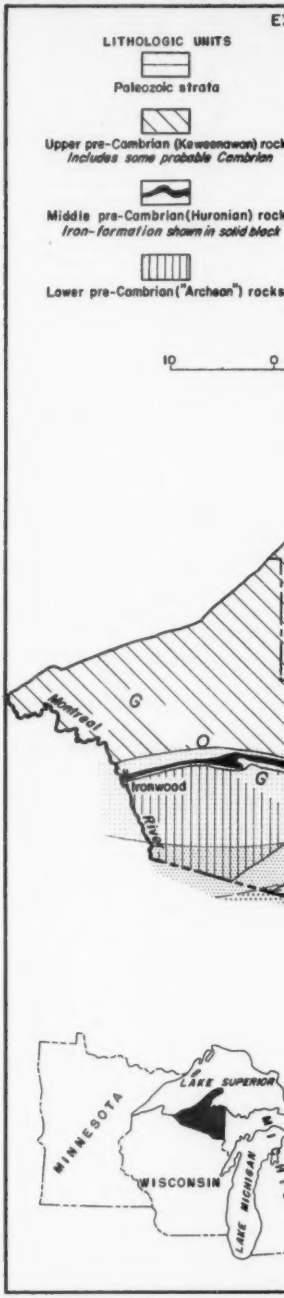

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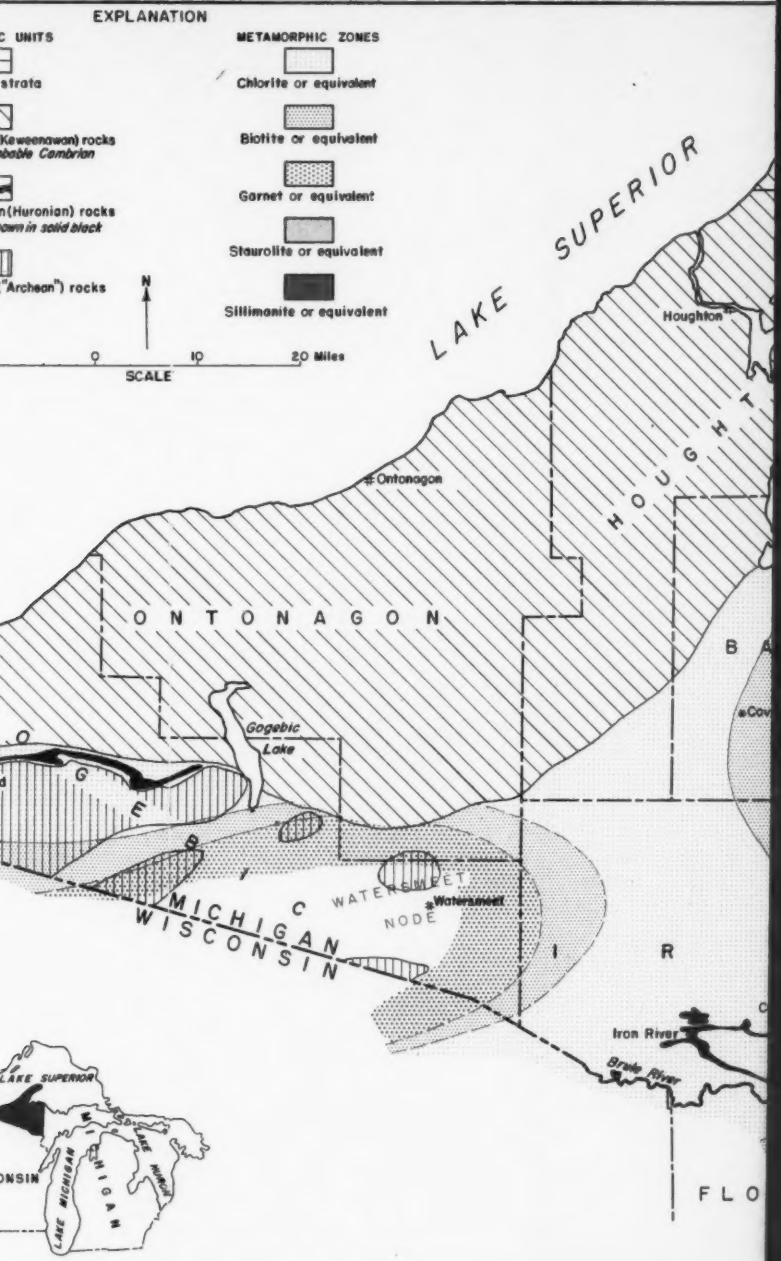

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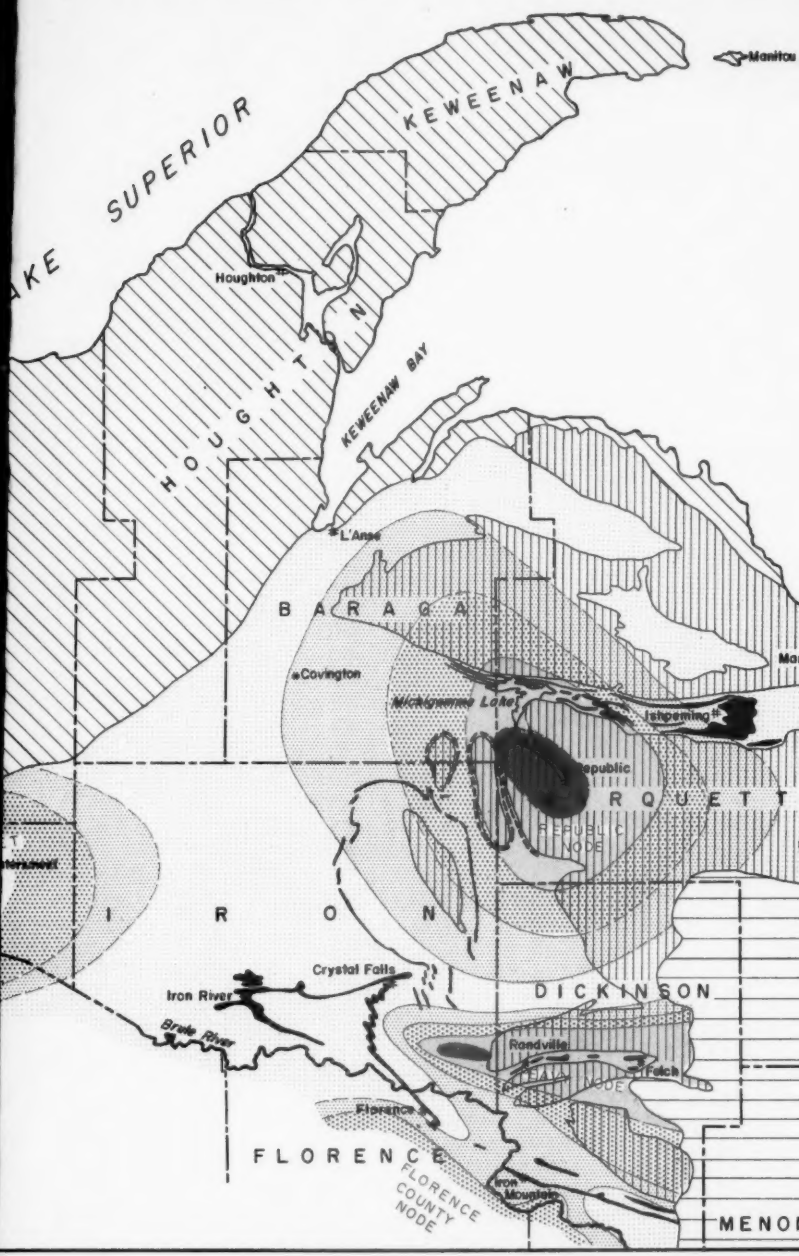

NORTHERN MICHIGAN, SHOWING METAMORPHIC ZON

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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ZONES OF REGIONAL METAMORPHISM IN THE PRECAMBRIAN OF NORTHERN MICHIGAN

BY HAROLD L. JAMES

ABSTRACT

Precambrian rocks are exposed throughout an area of about 7500 square miles in northern Michigan. Of this area, approximately 3300 square miles is underlain by relatively unmetamorphosed Upper Precambrian (Keweenawan), about 2700 square miles by metamorphosed Middle Precambrian (Huronian), and about 1500 square miles by metamorphosed Lower Precambrian ("Archean"). Flat-lying or low-dipping strata of Paleozoic age overlap the Precambrian along the east margin of the area.

The metamorphism, which is shown most clearly by mineralogic changes in the Huronian sedimentary rocks, especially in the iron formations and the graywackes and slates, and in the post-Huronian basic intrusive rocks, occurred during a post-Huronian–pre-Keweenawan interval of orogeny and minor granite intrusion. At least one earlier period of major, intense metamorphism of pre-Huronian age (Algoman?) is recognized. In near-by areas of Wisconsin and Minnesota, a later thermal metamorphism is related to the intrusion of the upper Precambrian Duluth gabbro and equivalent masses;it is restricted to the immediate vicinity of the gabbroic bodies.

Zones of metamorphic intensity delineated by chlorite, biotite, garnet, staurolite, and sillimanite isograds or their equivalents are partly or completely developed around four nodes, two of which lie in immediately adjacent parts of Wisconsin. The zones range in width from less than a mile to about 30 miles, and metamorphism of low grade is areally dominant over that of intermediate and high grade. The principal iron-ore deposits of the region—the "soft ores"—are restricted to the lower metamorphic zones, whereas the material considered suitable as low-grade concentrating ore ("taconite") is restricted to the areas of high-grade metamorphism. The influence of metamorphism on grain size appears to be the controlling factor.

Analysis of thermal gradients inferred from the metamorphic zonation indicates that the heat required for metamorphism must have been derived from subjacent bodies of magma, but the metamorphic patterns show no clear relation to regional structure or to the exposed granitic intrusions of the same orogenic cycle. The granite is most abundant in the areas of strongest metamorphism, but field evidence shows that most of the masses were intruded after the metamorphism. Field evidence also shows that deformation and metamorphism are independent variables in the orogenic scheme for this particular region.

Retrograde metamorphism, not related to shearing, is widespread.

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Introduction

The geology of the Precambrian terrane of northern Michigan and adjacent areas has been fairly well known for 40 years, since completion of the series of U.S. Geological Survey monograph studies that culminated with publication of Monograph 52 (Van Hise and Leith, 1911). Variations in degree of metamorphism are noted in many of these early reports but are not systematically described. More extensive discussion is given by Richarz (1927a; 1927b; 1927c; 1930; 1932) and by Lamey (1934). The distribution of notably metamorphosed rock in Iron County is shown on the geologic map of Iron County (Barrett, *et al.*, 1929); the outer limit of metamorphism shown on that map coincides roughly with the biotite isograd as delineated in this paper. The Iron County map apparently is the only one previously published on which areal distribution of regional metamorphism is indicated for any part of northern Michigan, although the general areas of high metamorphic grade have been known for many years.

The present paper is not a product of systematic study of the metamorphism but rather is an outgrowth of general mapping by the U.S. Geological Survey. This work, done in cooperation with the Geological Survey Division of the Michigan Department of Conservation, has had as its main goal an understanding of the distribution and character of the iron formations and associated iron ores of the region. The area is one of the few mining regions of the world in which metamorphic zonation has direct practical application.

In general, bedrock is poorly exposed in northern Michigan. Outcrops are small and scattered, and in some parts of the area tens or even hundreds of square miles are without a single exposure. In consequence, it rarely is possible to "walk out" the transitions from one zone to another; the isograds given in this paper are, in effect, contours drawn so as to enclose isolated points determined to be of equivalent metamorphic rank, rather than lines of observed transition. Approximately 2500 thin sections have been examined, but a large number of these are from small mining districts. Some outlying areas were poorly sampled, some because of lack of opportunity but most because of scarcity of outcrop. Figure 1 shows the distribution of samples. Previously published reports, particularly Monograph 19 (Irving and

FIGURE 1.—TOWNSHIP AND RANGE MAP OF NORTHERN MICHIGAN AND ADJACENT PARTS OF WISCONSIN

Showing a generalized distribution of samples examined petrographically. Each dot marks a section from which at least one sample was taken; single dots may represent one sample or a hundred. Many samples yield no critical mineral assemblages. Locations of specific descriptions from literature shown by "X" (only those in critical positions shown). Positions of isograds shown: B—biotite: G—garnet; St—staurolite; Si—sillimanite.

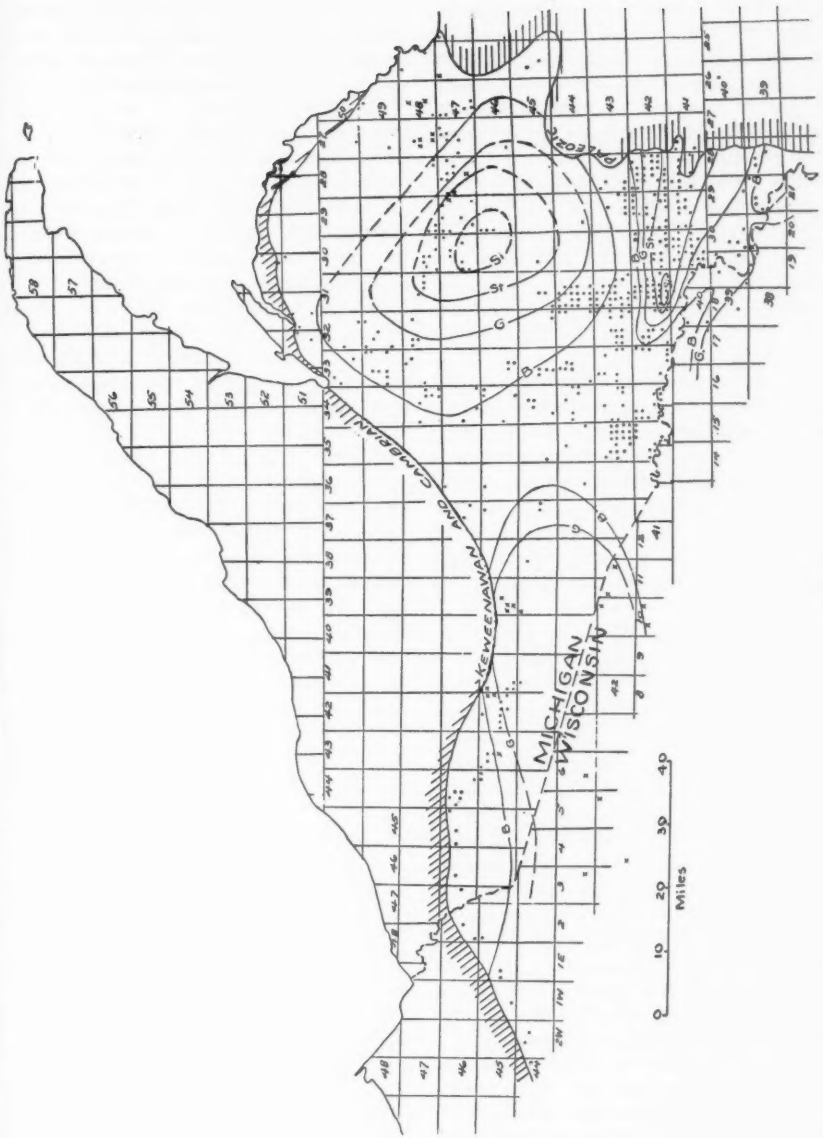


FIGURE 1.

Van Hise, 1892), Monograph 28 (Van Hise and Bayley, 1897), Monograph 36 (Clements and Smyth, 1899), and Publication 18 of the Michigan Geological Survey (Allen and Barrett, 1915) have been valuable sources of specific information. Examples of metamorphism in Iron and Dickinson counties predominate. These areas have been mapped in detail by the U.S. Geological Survey, and the writer is deeply indebted to colleagues for much factual information as well as for direct assistance and advice; specific mention must be made of contributions by R. W. Bayley, L. C. Clark, J. F. Freedman, J. E. Gair, Arthur Lachenbruch, C. A. Lamey, F. J. Pettijohn, James Trow, and K. L. Wier.

The material presented in this paper by no means represents a completed study. Topics such as metamorphic changes within specific stratigraphic units, optical and chemical variations within mineral species, and many other aspects of the metamorphic pattern deserve more thorough treatment. At best, it is hoped that the present study will serve as a framework for more detailed future investigations.

Geology

General Outline

Approximately 7500 square miles of northern Michigan is underlain by Precambrian rocks (Pl. 1). The geologic boundaries on Plate 1 are taken from the geologic map of northern Michigan published in 1936 (Martin), with some modifications, chiefly in Iron and Dickinson counties. Flat-lying or low-dipping Paleozoic strata overlap the Huronian and pre-Huronian rocks on the east and Keweenawan on the north. The Precambrian is divided into three major parts (Table 1).

Lower Precambrian ("Archean") rocks, predominantly granite gneiss, amphibolite, and schist, form islandlike masses surrounded by Huronian metasedimentary and metavolcanic strata. The latter are commonly tightly folded along structural axes generally trending westerly or northwesterly. To the northwest and north is a thick section of volcanics and sandstones in part of Keweenawan and in part of possible Cambrian age. The only area where the precise age is critical to the study of the metamorphic zones is in southern Ontonagon County, east of Lake Gogebic, where younger rocks overlap the isograds. Here the overlapping rocks are typical Keweenawan traps, which are relatively unmetamorphosed.

Three major intervals of orogeny, metamorphism, and igneous intrusion of pre-Keweenawan age have been recognized. Keweenawan granite occurs as differentiates of gabbroic masses near Mellen, Wisconsin, and Duluth, Minnesota, but in northern Michigan this episode of intrusion is represented only by unmetamorphosed diabase dikes.

The metamorphic zones (Pl. 1) are related to the youngest of the three major orogenic intervals, generally referred to as the Killarney revolution from assumed equivalence with the post-Huronian orogeny and Killarney granite intrusion on the north shore of Lake Huron. (*See* Collins, 1925.) To this orogeny, which involved Huronian strata and post-Huronian basic intrusives, Leith *et al.* (1935, p. 20) assigned a late Keweenawan age, evidently on the basis of (1) assumed equivalence of the granite associated with the Keweenawan gabbro sheet near Mellen, Wisconsin to other post-Huronian granites, and (2) the apparent structural conformity between the Huronian and the Keweenawan on the Gogebic range. Zircon age determinations, made by Howard W. Jaffe of the U.S. Geological Survey on two samples of granite from Mellen and on one sample of post-Huronian granite from Iron County, indicate an age of about 575 million years for the Keweenawan granite and of 820 million years for granite classed here as post-Huronian-pre-Keweenawan. Major structures in the Huronian such as the Sunday Lake fault originated prior to the Keweenawan (Hotchkiss, 1919), so that despite the general conformity of strike and dip, an interval of structural disturbance did intervene between the Huronian and the Keweenawan.

Differences in metamorphism between the Huronian and the Keweenawan in the Gogebic range area are not pronounced, but they are very real. The Huronian rocks, and the many post-Huronian basic intrusives, are within the chlorite zone of metamorphism; as a result, the basic intrusives are completely altered to chlorite-albite-epidote-amphibole rocks whereas

the Keweenawan flows of similar composition are essentially unaltered. The "Killarney" epoch in this area must be pre-Keweenawan.

In northern Michigan the granite emplaced during or immediately after the post-Huronian–pre-Keweenawan orogeny is of minor importance, though it does occur as dikes and small masses over a wide area. In contrast, during the pre-Huronian epoch of orogeny (Algoman), when great batholiths of granite gneiss and related migmatite developed, throughout much of the region the older rocks were either obliterated by granitization or were eroded before deposition of the Huronian series. Pre-Huronian sedimentary and volcanic strata are preserved in places, notably in central Dickinson County (James *et al.*, 1952), where conglomerate, arkose, schist, iron-formation, and metavolcanic rocks rest with profound unconformity upon the granitic gneiss (Laurentian?). Abundant quartzite pebbles in the basal conglomerate and inclusions of quartzite in the gneiss provide evidence of still older sedimentary series. The northern Michigan terrane is clearly a palimpsest; each orogenic interval has obscured the imprint of preceding events. The metamorphism that forms the subject of this paper, in areas of pre-Huronian rocks is superimposed upon older metamorphic patterns and has modified or obliterated them. The effects of the younger metamorphism on these previously metamorphosed rocks and on the older granite have not been studied systematically; attention is focused on the more obvious changes in the Huronian strata and on the pre-metamorphic basic intrusives that cut the Huronian.

TABLE 1.—SUCCESSION OF ROCKS IN NORTHERN MICHIGAN

Major divisions	*Commonly used designations*		*Principal lithologies*
Upper Precambrian	Keweenawan		Sandstone, conglomerate, and extrusive volcanics
	UNCONFORMITY		
Middle Precambrian	Killarney		Granitic rocks
			Basic intrusives
	Huronian	Upper Huronian	Graywacke, slate, basic volcanics, locally iron formation
		Middle Huronian	Iron formation, slate, quartzite
		Lower Huronian	Dolomite Quartzite
	UNCONFORMITY		
Lower Precambrian	"Archean"	"Algoman"	Gneissic granite
			Metasedimentary and metavolcanic rocks
		"Laurentian"	Granite gneiss

Middle Precambrian Rocks

Most of the Middle Precambrian rocks belong to the Huronian series. In Michigan, the Huronian is divided into three parts, the lower, the middle, and the upper, which are separated by slight to moderate unconformities.

LOWER HURONIAN ROCKS: The lower Huronian comprises two major units: a thick basal quartzite (the Mesnard, Sturgeon, and Sunday quartzites of separate localities), and an equally thick dolomite (the Kona, Randville, and Bad River dolomites, and the Saunders formation). Both units contain some slaty members. The aggregate thickness of the two units is typically about 4000 feet, but in many places these strata are absent because of nondeposition or post-dolomite erosion.

MIDDLE HURONIAN ROCKS: The middle Huronian strata in most of northern Michigan consist of basal clastic beds overlain by iron formation. Representative clastic formations are the Siamo slate of the Marquette range, the Palms quartzite of the Gogebic range, and the Felch schist of the Felch Mountain district. These commonly are conformable or nearly so with the lower Huronian rocks, but in many places, as in the Gogebic range, the basal beds of the middle Huronian rest directly on pre-Huronian granite gneiss or greenstone. The basal clastic formations range from 10 to 800 feet in thickness and from vitreous quartzite to graywacke and slate (or schist) in lithology. They grade upward into the iron formation—the varied and distinctive stratigraphic unit of the middle Huronian. Most iron-formation rocks consist of thin layers of chert (now crystalline quartz) alternating with layers in which the iron minerals, siderite, hematite, iron silicates, or magnetite are predominant. (*Note:* Descriptions are of unoxidized iron formation; actually, rocks seen most commonly in the field are oxidized equivalents.) The Negaunee iron formation of the Marquette range attains a maximum thickness of 2000 feet, whereas the Ironwood iron formation of the Gogebic range and the Vulcan iron formation of the Menominee and Felch Mountain districts rarely exceed 800 feet.

UPPER HURONIAN ROCKS: The epoch of chemical sedimentation now represented by the major iron-formation units was terminated by a structural disturbance that is marked by conglomerate in the Marquette range and (locally) in the Menominee range. In some places the middle and lower Huronian strata were completely eroded, and the upper Huronian rests on pre-Huronian crystalline rocks.

The upper Huronian section is made up chiefly of graywacke, slate, and basic volcanic rocks, but conglomerate, quartzite, and iron formation are common, particularly in the lower part. The principal stratigraphic unit is the Michigamme slate and its correlatives in the Gogebic range area (the Tyler slate and the Paint slate of Allen and Barrett, 1915). This rock underlies a greater area than does any other pre-Keweenawan unit. The exposed parts of the Michigamme slate and correlatives consist of graywacke and slate in about equal proportions. The graywackes are dark gray, massive, and fine- to medium-grained; cross-bedding and ripple-marking are absent, but graded bedding, in units ranging from a fraction of an inch to 2 feet in thickness, is common. The slates are light to dark gray and transitional in grain size into the graywackes with which they are interbedded. Calcareous concretions are present in some layers; they are elliptical in cross section and range from an inch to several inches in diameter. Bedding is commonly indistinct or subordinate to slaty cleavage as the obvious structure. Most graywacke beds show no cleavage, although in graded beds the finer-grained upper parts may show well-developed cleavage, commonly subparallel with bedding (Pl. 2, fig. 1).

The Michigamme slate and its correlatives are probably about 5000–10,000 feet thick.

Basic volcanic rock, now mainly greenstone, forms several thick units in the upper Huronian. The major masses lie in Iron and Dickinson counties (Pentoga belt, Quinnesec belt, Spread Eagle-Mastodon belt, Paint River belt) with thicknesses up to several miles. Much of this rock shows agglomeratic or pillow structures, and submarine origin is probable. Most of the extrusive volcanic rock in the region is basaltic although limited parts of the Hemlock greenstone in eastern Iron County and the Clarksburg formation in the Marquette district are intermediate or even rhyolitic.

POST-UPPER HURONIAN BASIC INTRUSIVES: Metamorphosed diabasic and gabbroic dikes and sills that cut both Huronian and pre-Huronian rocks are abundant throughout northern Michigan. They are numerous in the Marquette district; many of the rocky hills in the vicinity of Ishpeming are outcrops of a faulted sill (the "diorite" of local terminology) that is between 500 and 1000 feet thick. One

mass in eastern Iron County is about 5 miles long and three-quarters of a mile thick. Because of their uniformity of composition and wide distribution, the metamorphosed basic intrusives have been valuable in establishing metamorphic grade in areas otherwise lacking in "sensitive" rocks—as, for example, in areas underlain predominantly by pre-Huronian granite gneiss.

Metamorphic Facies

General

The post-Huronian-pre-Keweenawan metamorphism is similar to that of the classic areas of the Scottish Highlands for which the concept of regional metamorphic zones was developed by Barrow (1893; 1912) and later amplified by Tilley (1925), Kennedy (1949), and others. Of the six zones—chlorite, biotite, garnet, staurolite, kyanite, and sillimanite—defined in the Highlands, all except kyanite are represented in zones ranging from about a mile to about 20 miles in width. The lowest-grade zone, that of chlorite, is by far the most extensive, and in most of the region primary features of the rocks are more striking than those of secondary origin. In contrast with the Highlands, however, there is no central "zone of injection"; furthermore, the metamorphic zones apparently have not been structurally dislocated, which in large part accounts for the exceedingly simple patterns of distribution. The metamorphism is unusual in that it was not synchronous with deformation; in Harker's terminology, it would be classed as metamorphism under deficient shearing stress (Harker, 1939, p. 230). Perhaps "regional thermal metamorphism" would be more appropriate.

Four nodes of high-grade metamorphism are recognized within or adjacent to the area (Pl. 1): the Republic node, centering near the town of Republic in southwestern Marquette County; the Peavy node, centering near Peavy dam in southeastern Iron County; the Florence County node, in adjacent Wisconsin; and the Watersmeet node in southeastern Gogebic County.

(1) Republic node. Delineation of a sillimanite zone in the Republic district is based chiefly on features shown by the iron formation, and at best the position of the isograd is highly approximate. The Michigamme slate—probably the only rock that would yield sillimanite—though not exposed is assumed to be present between Republic and the south end of Lake Michigamme, and an erratic boulder of sillimanite-bearing Michigamme slate derived from this covered area was found 7 miles west-northwest of Republic.

Staurolite-rich rocks are abundant, so that the position of the staurolite zone is well established, but the garnet zone is very poorly defined. Some of the Michigamme slate placed in the upper part of the biotite zone in the area between Covington and Lake Michigamme, however, may be in the garnet zone even though no garnet could be found in the exposed rocks. The rocks exposed in the road cut at Tioga Creek, on highway M-28 10 miles east of Covington, for example, is a biotite-muscovite schist that contains calcareous concretions. The concretions show reaction borders of needle-like amphibole such as are found in garnetiferous rocks elsewhere, whereas in definite biotite-zone rocks, similar concretions show no reaction boundaries. The best examples of garnet-zone metamorphism in the Republic node are the basic igneous rock, iron formation, and dolomite exposed along the Fence River in T. 45 N., R. 31 W., northeastern Iron County.

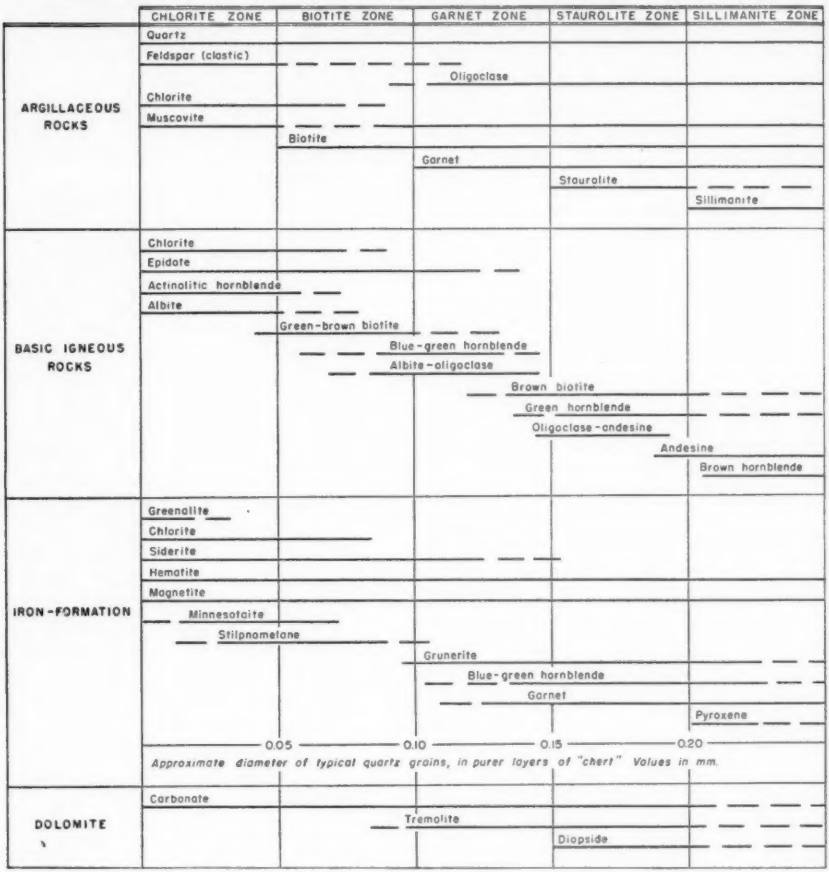
The center of the node lies near the contact of the Huronian strata with granite and gneiss. Evidently the metamorphism is not genetically related to the contact, because the abundant basic dikes that cut both the granite and the Huronian strata are entirely metamorphosed, and the isograds cross the continuation of this contact elsewhere.

Closure of the isograds in the area southeast of Republic—an area largely mantled by glacial drift—is inferred from the occurrence of low-rank rocks in T. 45 N., R. 25 W., and T. 43 N., R. 28 W.

(2) Peavy node. The sillimanite zone of the Peavy node is restricted to a small area

TABLE 2.—MINERAL ASSEMBLAGES OF SOME COMMON ROCKS IN THE METAMORPHIC ZONES OF NORTHERN MICHIGAN

Dashed lines indicate uncertainty as to classification. Some minor minerals are not shown



of southeastern Iron County, but the zone of high-rank metamorphism extends eastward in a widening pattern and continues beneath the Paleozoic strata. Coarse-grained garnetiferous schist, presumably part of the Michigamme slate, has been drilled in T. 40 N., R. 26 W.

Metamorphic gradients in the western part of the node are steep. At Peavy dam on the Michigamme River, the Michigamme slate consists of sillimanite-staurolite schist, but at Lower Hemlock Falls, only 3½ miles south, the rock is of biotite grade. The gradient may be even steeper to the north. A variety of post-Huronian igneous rocks forms scattered exposures near the center of the sillimanite zone. According to R. W. Bayley (Personal communication), they range in composition from ultrabasic to granitic. The gabbroic rocks are pre-metamorphic, and most of the granite is post-metamorphic.

(3) Florence County node. An area of high-rank metamorphic rocks lies south of the town of Florence, but it has not been

studied in sufficient detail to warrant delineation of isograds above that of garnet. The garnet isograd has been established by reference to iron formation.

(4) Watersmeet node. The metamorphic rocks of southern Gogebic County lie at the eastern end of a metamorphic high that extends westward into Wisconsin for at least 40 miles. Information is very scarce concerning the rocks of this belt, especially those in the higher zones, because of the complete absence of outcrop in areas measurable in hundreds of square miles. In the Michigan part of the belt, the biotite and garnet isograds can be established with fair accuracy only in the area south of Lake Gogebic. The eastern terminus of the metamorphic high is defined on the basis of very few samples (Fig. 1).

Anomalies in the metamorphic pattern are few. Most are the result of contact metamorphism of intrusive rocks and are confined to the immediate vicinity of such intrusives. Very locally, some of the pre-metamorphic basic igneous rocks are incompletely metamorphosed and contain both relict primary minerals and minerals of secondary origin. Such rocks may also contain phases that are not strictly in keeping with the metamorphic level of the area; for example, a metagabbro from the lower part of the biotite zone in sec. 21, T. 47 N., R. 27 W., contains grains of oligoclase-andesine with cores of labradorite and rims of albite, also a blue-green hornblende, pseudomorphic after pyroxene, that is of a type characteristic of rocks in slightly higher metamorphic zones. Some apparent anomalies in the metamorphic pattern are due to preservation of minerals that originated in an earlier metamorphic cycle. For example, the pre-Huronian greenstone in sec. 6, T. 47 N., R. 24 W., which bounds the Marquette trough on the south, is definitely within the chlorite zone, yet it contains green hornblende characteristic of higher metamorphic levels. From textural relations, it is evident that the rock prior to the post-Huronian metamorphism was an amphibolite. The feldspar of the amphibolite has broken down to albite and clinozoisite, but the hornblende is preserved without appreciable modification.

The relationships of critical mineral assemblages to the mapped zones are summarized in Table 2. Many of the stability ranges given in the table are mere estimates, and for minerals that form solid-solution series the change in physical properties is obviously continuous.

The Graywacke-Shale Suite

The graywackes and slates of upper Huronian age, which underlie a larger area in northern Michigan than does any other pre-Keweenawan unit, resemble the pelitic and subpelitic rocks of the Dalradian and Moine schists in Scotland and many other geosynclinal stratigraphic groups. These rocks contain the index minerals that define the major metamorphic zones. The chemical compositions of several typical rocks of the graywacke-shale suite from northern Michigan are given in Table 3.

CHLORITE ZONE: In the lowest grade of metamorphism represented—that of chlorite—the slates are very fine-grained and consist chiefly of chlorite, sericite, and fine clastic material. The graywackes are mineralogically similar but contain variable amounts of clastic feldspar, both plagioclase and orthoclase, and locally coarse patchy calcite. Epidote, as small irregular grains, is not common but has been observed in some slides. Preservation of original clastic texture is largely a function of grain size; in the fine-grained graywackes in which the original grains were silt-size (less that 0.1 mm) the clastic outlines are only poorly shown, whereas in coarser-grained graywacke the grains are well defined. In virtually all specimens examined, however, the clastic grains are irregularly embayed by the matrix minerals—chlorite, sericite, or carbonate (Pl. 3, fig. 1). In some rocks, the depth of penetration of this peripheral alteration is not directly related to the degree of metamorphism, and it is possible that the alteration is a chemical reaction that may have started and possibly even completed during diagenesis and lithification of the rock. Similar marginal replacement is mentioned by Pettijohn (1949, p. 245–248) in rocks that appear essentially unmetamorphosed. In some rocks the preferred orienta-

TABLE 3.—CHEMICAL COMPOSITION OF ROCKS OF THE GRAYWACKE-SHALE SUITE IN NORTHERN MICHIGAN

	1	2	3	4	5	6	7	8
SiO_2	59.19	49.85	51.38	57.94	60.03	66.51	55.90	60.56
Al_2O_3	14.61	13.88	23.89	18.88	17.85	15.31	19.31	18.43
Fe_2O_3	1.51	3.75	2.05	1.26	1.14	0.50	0.95	2.14
FeO	11.28	14.10	5.01	6.73	7.16	5.22	7.83	6.40
MgO	2.94	3.32	2.71	3.21	3.15	2.45	4.01	3.39
CaO	0.09	0.20	0.24	0.91	0.44	2.00	1.17	1.33
Na_2O	0.12	0.10	0.59	1.69	1.64	3.08	1.73	1.99
K_2O	2.38	2.74	7.08	3.45	3.41	2.72	4.91	3.09
H_2O^-	0.07	0.14	0.21	0.06	0.11	0.03	0.19	0.06
H_2O^+	4.69	4.90	4.66	3.87	3.63	1.21	2.77	1.48
TiO_2	1.45	1.45	1.22	0.92	0.95	0.66	0.85	0.82
CO_2	1.25	4.09	0.14	0.06	0.12	0.01	none	0.01
P_2O_5	0.07	0.09	0.16	0.22	0.09	0.15	0.18	0.18
MnO	0.10	0.24	0.02	0.07	0.03	0.06	0.04	0.04
C	0.25	0.69	0.16	0.52	0.19	n.d.	n.d.	n.d.
S	0.08	1.51	none	none	0.01	n.d.	n.d.	n.d.
	99.98*	100.29*	99.52	99.79	99.95	99.91	99.87	99.92

1. Siltstone from "footwall" sequence, Iron River district, Michigan. Chlorite zone of metamorphism. Charlotte Warshaw, analyst.

2. Sericitic slate from "footwall" sequence, Iron River district, Michigan. Chlorite zone of metamorphism. Charlotte Warshaw, analyst.

3. Slate from Tyler slate, Gogebic district; railroad cut of Soo line in the NE¼ sec. 31, T. 46 N., R. 2 E., Wisconsin. Chlorite zone of metamorphism. R. H. Nanz, analyst. (Nanz, 1953)

4. Slate from Michigamme slate, road cut on U. S. Highway 141, approximately 1.6 miles north of the southern boundary of Baraga County. Biotite zone of metamorphism. R. H. Nanz, analyst. (Nanz, 1953)

5. Slate from Michigamme slate, road cut on U. S. Highway 141, approximately 4.4 miles north of southern boundary of Baraga County. Biotite zone of metamorphism. R. H. Nanz, analyst. (Nanz, 1953)

6. Biotite granulite from Michigamme slate at Peavy dam, sec. 32, T. 42 N., R. 31 W., Iron County. Sillimanite zone of metamorphism. Lucille M. Kehl, analyst.

7. Sillimanite-bearing biotite schist, from same location as above. Lucille M. Kehl, analyst.

8. Staurolite schist, from same location as 6. Lucille M. Kehl, analyst.

* Corrected O for S

tion of chlorite is pronounced (Pl. 3, fig. 1) and appears to be of metamorphic origin.

The rocks of shale composition in the region show actual or incipient slaty cleavage controlled by oriented mica and, to a lesser degree, by chlorite. The cleavage is of the axial-plane type, and owing to the prevalence of steep or vertical dips it is most commonly parallel to bedding or nearly so; only in the axial regions of folds does the cleavage form at a distinct angle to bedding.

Chloritoid, a mineral of uncertain significance in the metamorphic scheme, is reported by Lamey (1935, p. 1145) in a conglomerate in the Palmer area, about 6 miles southeast of Ishpeming. Other evidence indicates that the area is in either the upper part of the chlorite zone or, less likely, the lower part of the biotite zone.

BIOTITE ZONE: Biotite forms in almost all rocks of the graywacke-shale group within the appropriate metamorphic environment (Pl. 3, fig. 2). The porphyroblasts are uniformly distributed throughout a given layer, and although textural relationships do not suggest that the biotite forms at the expense of any specific pre-existing material, the increase in biotite coincides with a decrease in chlorite and especially in muscovite. The biotite is a common brown variety; greenish and reddish

shades are rare. In the upper part of the biotite zone the muscovite is notably coarser-grained and the rock more homogeneous in texture. The argillaceous layers become lustrous phyllites or schists but the interbedded graywacke remains almost unchanged in outward appearance. Graywacke and slate of the biotite zone are well exposed in road-side outcrops along U. S. Highway 141 south of Covington, and in the area immediately east of Covington.

GARNET ZONE: Garnet is not as dependable an index mineral as biotite, and is absent from much of the argillaceous rock within the designated zone. The garnet is the common pinkish to pinkish-yellow variety, presumably almandine. It occurs as isolated subhedral crystals, but in many rocks it forms irregularly shaped grains (Pl. 3, fig. 3). Sieve structure is common. Only rarely has the garnet thrust aside other minerals during growth, and the evidence indicates no rotation during growth. Biotite and muscovite persist and are dominant constituents of some layers. Chlorite is absent in the higher parts of the zone, but in the lower part it may be abundant.

The rocks at this stage differ but little in appearance from the graywacke and slate of lower metamorphic zones, except that the argillaceous layers are more strongly schistose. Clastic texture, however, is preserved only in the coarser-grained grits; the average graywacke, though similar in color and grain size to more weakly metamorphosed counterparts, now is a granulite with interlocking quartz and feldspar grains. Layers that originally possessed graded bedding show reversal in grain size: the upper parts, originally more argillaceous and finer-grained than the sandy lower parts, become coarser-grained by virtue of a composition that permits development of abundant mica, whereas the sandy lower parts develop a granulitic texture no coarser than that of the original material.

STAUROLITE ZONE: The bulk compositional requirements necessary for formation of staurolite are such that this index mineral is found only in a few argillaceous rocks in northern Michigan. It is abundant in some beds, however, and not uncommonly it is present in the originally finer-grained upper parts of graded beds, thus increasing the contrast in grain size with the granulitic lower parts. The staurolite is typical of that described by Harker (1950, p. 225):

> "Staurolite, appearing at first in small grains, soon develops into large idioblastic and often porphyroblastic crystals, which are commonly interpenetrating twins. They are often crowded with inclusions of quartz which has presumably become entangled in the building up of large staurolite crystals from numerous small grains" (*See* Pl. 3, fig. 4.)

The similarity in composition between staurolite and chloritoid would suggest that the latter mineral would be equally common in a lower zone of metamorphism and that there might be a paragenetic relationship between the two minerals. Such, however, is not the case; chloritoid is a rare mineral in the region, and no evidence of development of staurolite from chloritoid has been seen in any of the sections studied.

Kyanite, so often associated with staurolite elsewhere, is absent in the area. That its absence is not due entirely to lack of appropriate bulk composition in the rocks is shown by the abundant development of its dimorph, andalusite, in some of the staurolite schists. The andalusite-staurolite rock (Pl. 2, fig. 2) is found in several widely separated localities but is most abundant in Marquette County, near the south end of Lake Michigamme. The stratigraphic control of the andalusite-staurolite rock generally is obvious. The andalusite in thin section shows the typical sieve structure. Unlike the staurolite, which has well-defined crystal outlines, the andalusite is present as augen-shaped forms; in some outcrops the rock resembles a highly sheared conglomerate, with micaceous schist wrapped around distorted lumps of andalusite. Kyanite, not yet reported from northern Michigan, is known to be present in parts of Wisconsin adjacent to the Waters-meet node in the western part of the map area; Allen and Barrett (1915, p. 112, 120) describe this mineral in T. 42 N., R. 4 E., and in T. 42 N., R. 10 E. The two kyanite occurrences probably lie in the normal position for a kyanite zone, above that of garnet.

Garnet is present in most rocks within the staurolite zone, and is exceedingly abundant in some layers (Pl. 3, fig. 5). The garnet commonly is a more deeply colored variety than that within the garnet zone proper but is

similar in habit. Some of the biotite is molded around the garnets, but there is little or no evidence to indicate thrusting aside during growth, or rotation. Biotite is the predominant mica, though some muscovite is generally present.

As in the garnet zone, the original graywacke layers are not notably different in appearance from those in the lower zones of metamorphism. The rock is massive, gray, and fine- to medium-grained, without schistose or gneissose structure. Original textures are entirely lost, however, and in thin section the quartz and feldspar (generally oligoclase) form an interlocking mosaic; the rock is a granulite, as that term is used by the British petrologists. Except for graded bedding, the only structure other than the layering that is preserved is that of originally calcareous concretions (Pl. 2, fig. 3). These concretions have not been studied petrographically, but resemble those described by Pettijohn (1940).

SILLIMANITE ZONE: The only area in which sillimanite-bearing rocks are known to be exposed is at Peavy dam, in the southeastern part of Iron County. Most of the rock in the vicinity of the damsite is massive biotite granulite (graywacke) with interbedded micaceous sillimanite-staurolite schists; stratigraphically these beds are part of the Michigamme slate of upper Huronian age. Sillimanite was found also in a large glacially transported block of staurolite-andalusite schist 7 miles west-northwest of Republic, in western Marquette County. The source area for the erratic must have been in the narrow belt of upper Huronian strata that lies between Republic and the south end of Michigamme Lake, which is an area essentially devoid of outcrop. Similar andalusite-staurolite rock, but without sillimanite, is exposed at the south end of the lake.

Three analyses of the Peavy dam rocks are given in Table 3 (columns 6, 7, 8). The modes of two thin sections for each of these analyzed rocks are tabulated in Table 4. The quartz and feldspar that form the groundmass mosaic are equidimensional and about 0.2 mm in diameter. The feldspar is oligoclase (approximately An_{18}) and only a few grains show twinning; in some slides, the plagioclase shows a slight but definite gradational zoning to a more albitic rim. The biotite is brown, forms large flakes about 0.5 mm in length with marked preferred orientation, and most grains show numerous dark haloes around tiny grains of zircon. The muscovite occurs as large clear flakes, 1 mm or more in length, that typically lie athwart the cleavage direction defined by the biotite. The garnet and staurolite form porphyroblasts of typical form and appearance; the garnets are rarely more than 0.5 mm in diameter, but the staurolite forms grains up to 10 mm in length. The sillimanite is most abundant in the more micaceous beds in association with staurolite. On cleavage surfaces it forms thin rods and lenses commonly oriented parallel to the regional linear structure. In thin section it appears as clusters of fine needles (Pl. 3, fig. 6). The sillimanite bears no systematic paragenetic relationship to other minerals in the rock.

TABLE 4.—MODES OF ANALYZED SCHISTS AND GRANULITE

Analysis number	Quartz	Biotite	Muscovite	Plagioclase (An_{18})	Garnet	Staurolite	Sillimanite
6	62.8	21.5	5.6	8.5	1.6	—	tr.
7	35.9	40.7	7.6	9.4	3.0	0.3	3.1
8	46.3	33.0	2.0	4.3	1.0	13.3	tr.

Turner and Verhoogen (1951, p. 457) suggest that sillimanite forms as a product of the reactions.

$$\text{Staurolite} + \text{Quartz} \rightarrow \text{Almandine} + \text{Sillimanite} + H_2O$$

$$\text{Muscovite} + \text{Quartz} \rightarrow \text{Orthoclase} + \text{Sillimanite} + H_2O$$

A third possible reaction is the simple transformation of kyanite to sillimanite. These reactions, like those that produce other index minerals, need not occur at the same temperature (Yoder and Eugster, 1953), so that in effect there is more than one sillimanite isograd. Kyanite is not present in the Michigan rocks, and as muscovite is a stable constituent in the sillimanite schists, the staurolite → sillimanite reaction should apply. The phase relations based on this assumption are expressed

in Figure 2. Other combinations are possible, (*see* Wyckoff, 1952, p. 27–28) but in none is staurolite a stable phase in the presence of sillimanite. The conclusion seems justified, therefore, that although textural relationships compared with oligoclase in the enclosing rock. Apatite is abundant as small grains. The texture, however, is much similar to that of the enclosing rock, and the boundaries are indistinct in thin section.

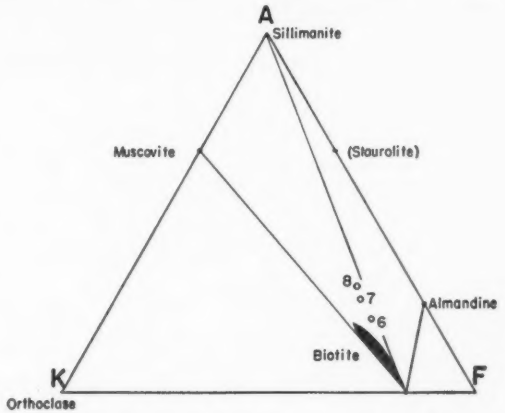


FIGURE 2.—AKF DIAGRAM FOR ROCKS WITH EXCESS Al_2O_3 AND SiO_2 AND DEFICIENT K_2O

Showing position of analyses 6, 7, 8 (Table 2). In thin sections studied, sample 7 contains 3.1 per cent sillimanite, 6 and 8 contain traces; sample 8 contains 13.3 per cent staurolite. All contain some garnet, a few per cent muscovite, and abundant biotite, in addition to quartz and oligoclase.

as seen in thin section offer no support to the view, staurolite is an unstable phase within the sillimanite zone. Beyond this, the lack of specific correlation between the predicted mineral assemblages for the plotted compositions and the observed assemblages is probably due to the fact that the analyzed samples are of such a size as to "average out" the inherent variations in the rock, variations that are, however, reflected in the mineralogy as seen in single thin sections.

The rocks retain much of the outward appearance of the graywacke and slate in zones of lower grade. Bedding is well preserved and some layers show original gradational grain (now reversed, with staurolite in the originally finer-grained, more argillaceous "tops" of some layers). Originally calcareous concretions are visible in some beds; at this particular locality they are strongly drawn out, with axial ratios of 10:2:1. The concretions are considerably different in mineralogy from the matrix, most notably in the composition of the plagioclase, which is labradorite (approximately An_{55}), as

Basic Igneous Rocks

General.—The basic igneous rocks are of two major groups: the extrusive greenstones, which form extensive, thick masses, and the pre-metamorphic basic intrusives that cut both Huronian and pre-Huronian rocks. Most of the basic igneous rocks originally were basalt, diabase, and gabbro. The extrusive rocks commonly show ellipsoidal and agglomeratic structures, and the bulk appears to be of submarine origin. The intrusive rocks are in the form of sills and dikes, and although they are quantitatively far less abundant than the extrusives, they are more widely distributed and consequently more valuable as a group to metamorphic mapping. In terms of metamorphic mineralogy, the original differences in form and degree of crystallization between the intrusives and the extrusives are unimportant; even within the lowest zones of metamorphism, the mineralogy of all types converges to a common assemblage. The metamorphism of the basic igneous rocks is somewhat similar to

that in the Scottish Highlands (Wiseman, 1934), but the Highland epidiorites contain garnet, whereas this mineral is not common in the Michigan rocks. The mineral assemblages developed from the basic igneous rocks in Michigan are more nearly like those in Vermont and New Hampshire described by Billings and White (1950).

Although the correlation chart (Table 2) shows that the mineralogic changes of the basic igneous rocks do not coincide with those of the graywacke-shale suite, it seems best to describe these changes in terms of the formal zones to permit direct comparison between rock types. If the basic igneous rocks alone were being considered, the facies classification of Eskola (1915, 1920, 1939) would be more suitable. This classification is related to the metamorphic zones approximately as follows:

Sillimanite zone	Amphibolite facies
Staurolite zone	
Garnet zone	Epidote amphibolite facies
Biotite zone	Greenschist facies
Chlorite zone	

CHLORITE ZONE: The largest part of the basic igneous rock in the region is mineralogically of the greenschist facies, within the chlorite zone. The completeness of the reactions by means of which the original pyrogenic assemblage was converted to secondary products is astonishing—of the hundreds of thin sections examined, fewer than 5 per cent contain a trace of relict minerals. Primary textures, however, are preserved in most specimens; depending upon the nature of the alteration products, the outlines of original grains may be visible in plane light and not with crossed nicols or vice versa.

The principal minerals are chlorite, pale-green hornblende (actinolitic hornblende), epidote-clinozoisite, and albite. Less abundant but typically present are sericite, "leucoxene" and sphene, magnetite, quartz, and calcite. Stilpnomelane was observed in one specimen, and a zeolite, apparently chabyzite, in two or three. The principal metamorphic minerals are found in all combinations and in widely differing proportions in all parts of the chlorite zone of metamorphism. Even within a single outcrop area of apparently homogeneous rock, the percentage of one of these minerals may range from 5 to 50. The pattern of alteration is not a consistent one: labradorite, for example,

PLATE 2.—MICHIGAMME SLATE IN OUTCROP

FIGURE 1.—GRAYWACKE BEDS IN CHLORITE ZONE

Shows graded bedding (tops of beds toward top of picture). Note that cleavage, closely spaced and nearly parallel to bedding in uppermost part of graded beds, swings into approximately 45-degree position in lower part. The continuous curve of cleavage reflects a perfect gradation in physical properties of the beds. Photograph by Lorin D. Clark

FIGURE 2.—ROUNDED ANDALUSITE AND EUHEDRAL STAUROLITE IN SCHIST

SE¼ sec. 20, T. 45 N., R. 30 W., Marquette County. Mottling on surface is due to lichen.

FIGURE 3.—METAMORPHOSED CALCAREOUS CONCRETIONS FROM SAME AREA AS FIGURE 2

Rock is in the staurolite zone.

PLATE 3.—PHOTOMICROGRAPHS OF METAMORPHOSED ARGILLACEOUS ROCKS

FIGURE 1.—GRAYWACKE IN CHLORITE ZONE

Chlorite replacing clastic grains shows strong preferred orientation. Ordinary light, ×65

FIGURE 2.—SLATE TYPICAL OF LOWER PART OF BIOTITE ZONE

With porphyroblasts of brown biotite in quartz-chlorite-muscovite matrix. Ordinary light, ×30

FIGURE 3.—GRAYWACKE WITH IRREGULAR PORPHYROBLASTS OF GARNET

Ordinary light, ×35

FIGURE 4.—SCHIST FROM STAUROLITE ZONE

Euhedral crystal of staurolite, in matrix of quartz, oligoclase, and biotite. Andalusite with sieve structure at left margin. Ordinary light, ×30

FIGURE 5.—GARNET-BIOTITE-QUARTZ SCHIST

Staurolite zone. Ordinary light, ×15

FIGURE 6.—SILLIMANITE NEEDLES IN QUARTZ-BIOTITE-OLIGOCLASE SCHIST

From Peavy dam, Iron County. Ordinary light, ×65

FIGURE 1

FIGURE 2

FIGURE 3

MICHIGAMME SLATE IN OUTCROP

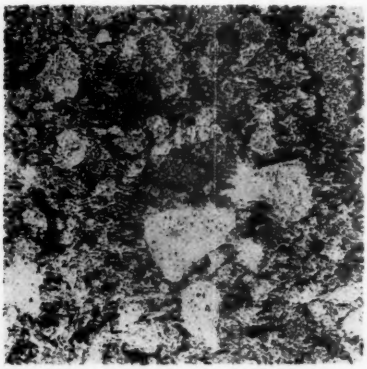
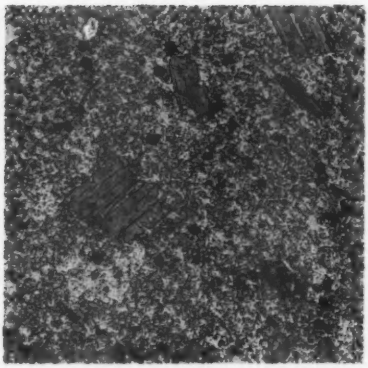


FIGURE 1



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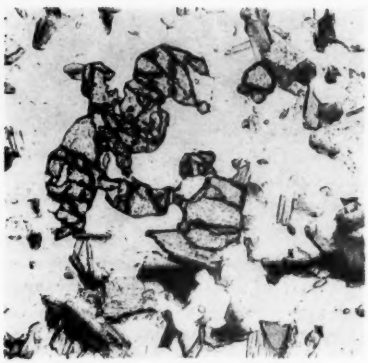

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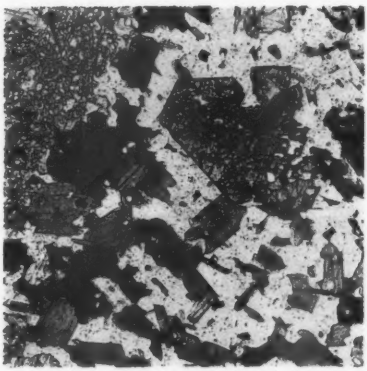

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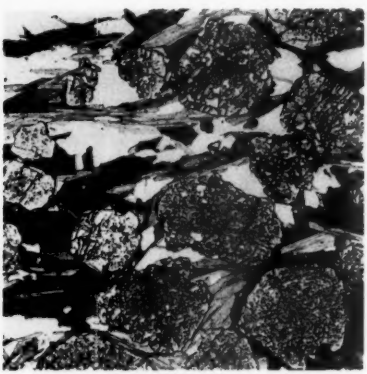

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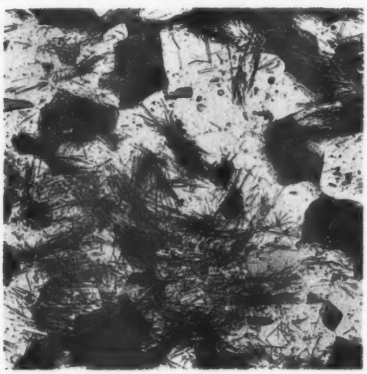


FIGURE 6

PHOTOMICROGRAPHS OF METAMORPHOSED ARGILLACEOUS ROCKS

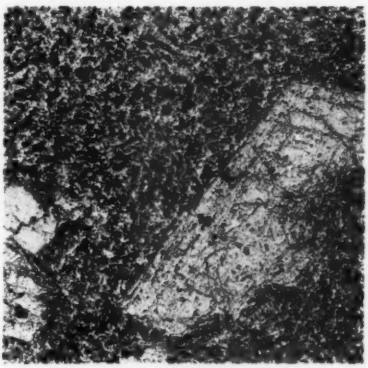
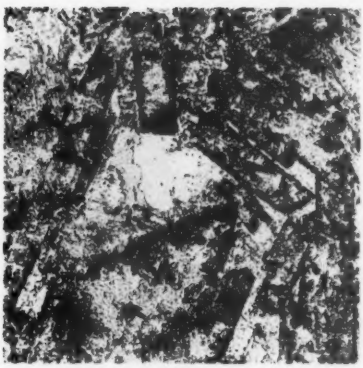


FIGURE 1



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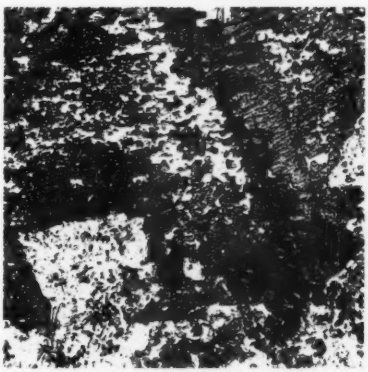

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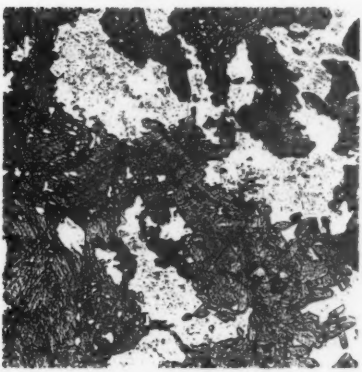

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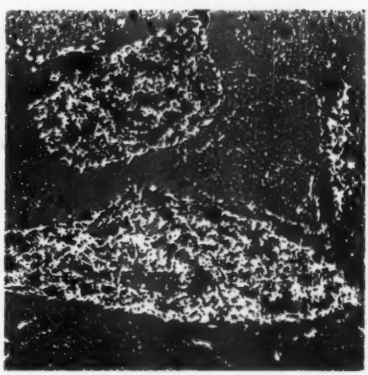

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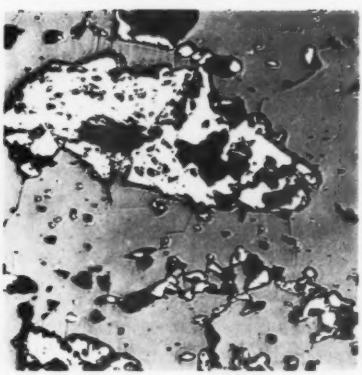

FIGURE 6

PHOTOMICROGRAPHS OF METAMORPHOSED BASIC IGNEOUS ROCKS AND OF IRON FORMATION

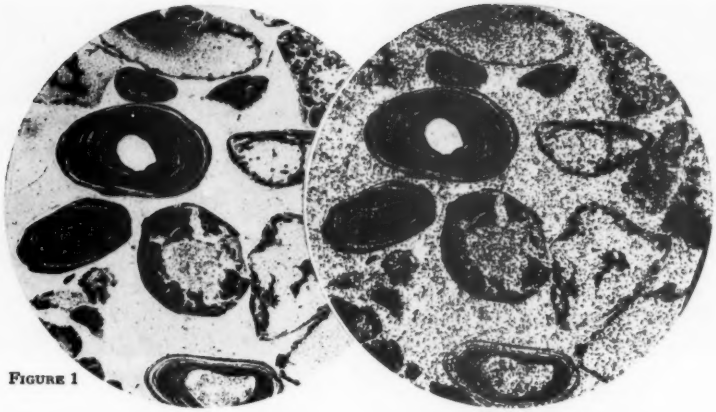

FIGURE 1

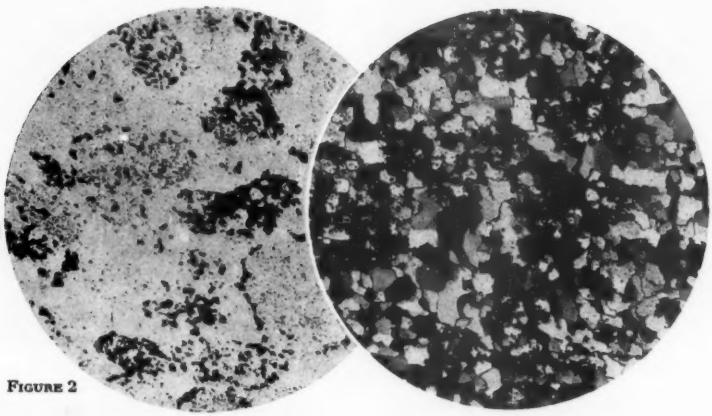

FIGURE 2

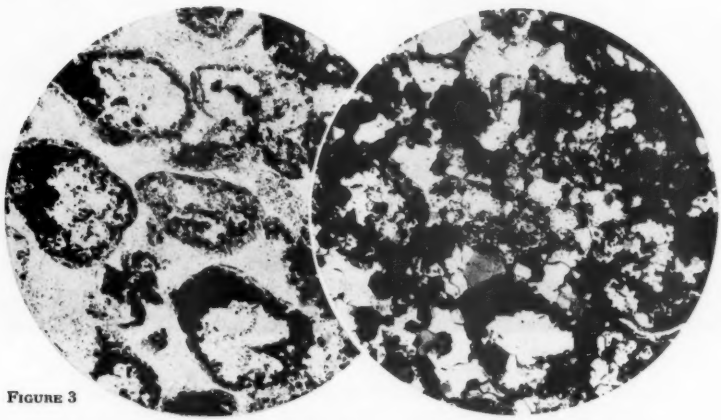

FIGURE 3

PHOTOMICROGRAPHS OF OOLITIC CHERT-HEMATITE IRON FORMATION FROM THREE ZONES OF METAMORPHISM

may be altered to albite with scattered grains of clinozoisite and shreds of chlorite, to a granular aggregate of clinozoisite, or to carbonate, although within a given specimen the alteration generally is of the same type. Characteristic views of basic igneous rock from the chlorite zone are shown in Figures 1 and 2 of Plate 4.

Where original minerals are preserved they are those common to basalts and diabase, namely pyroxene, plagioclase, and magnetite-ilmenite. The pyroxene, which appears more resistant to metamorphism than the feldspar, is pigeonite, with a small optic angle; the plagioclase is labradorite (around An_{55}). Greenstone containing abundant relict pyroxene and plagioclase is exposed in sec. 25, T. 43 N., R. 34 W., about half way between Crystal Falls and Iron River.

The secondary minerals commonly are very fine-grained. The chlorite is pale green, weakly pleochroic, and has very low birefringence—about 0.005 or less; much of it shows anomalous blue or purple interference colors under crossed nicols. The chlorite is less selective as an alteration product than any other secondary mineral; it occurs within original pyroxene and feldspar, or as a groundmass alteration. The hornblende also is pale green and weakly pleochroic (very similar to the chlorite in ordinary light), with C ∧ Z typically 16°–17°. In most specimens the hornblende is in fine shreds, but in some it forms plates pseudomorphic after pyroxene and comparable in size to the original mineral; in this latter occurrence the hornblende is a darker hue and more strongly pleochroic than normal for the zone. Wiseman's description (1934) of the Scottish epidiorites gives chemical and optical data on similar chlorite and hornblende. Minerals of the epidote-clinozoisite group are ubiquitous, generally as small grains or granular aggregates. Variations in birefringence indicate a considerable range in composition, and are apparently chiefly due to the character of the immediate host material rather than to regional

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PLATE 4.—PHOTOMICROGRAPHS OF METAMORPHOSED BASIC IGNEOUS ROCKS AND OF IRON FORMATION

FIGURE 1.—GREENSTONE, ORIGINALLY PORPHYRITIC BASALT

Original pyroxene phenocrysts now a fine-grained aggregate of pale-green hornblende and chlorite; groundmass is chlorite, epidote, leucoxene (black), and albite. Ordinary light, ×30

FIGURE 2.—METADIABASE, IN CHLORITE ZONE

Plagioclase laths now chiefly clinozoisite and chlorite; original pyroxene mainly pale-green hornblende. Albite in the groundmass, with some quartz. Ordinary light, ×40

FIGURE 3.—METADIABASE (EPIDOTE AMPHIBOLITE) FROM THE GARNET ZONE

Principally hornblende (dark gray) and oligoclase (white), with scattered grains of epidote, biotite, quartz, muscovite, apatite, and sphene. Large relict grain of skeletal magnetite (opaque). Ordinary light, ×35

FIGURE 4.—METADIABASE (AMPHIBOLITE) FROM THE STAUROLITE ZONE IN WESTERN MARQUETTE COUNTY

Rock occurs as dike in granite; now consists chiefly of green hornblende and andesine, with accessory biotite, sphene, and magnetite. Ordinary light, ×35

FIGURE 5.—POLISHED SECTION OF IRON FORMATION FROM THE BIRD EXPLORATION, EASTERN IRON COUNTY, IN UPPER PART OF CHLORITE ZONE

Granules of fine-grained hematite (white) in chert matrix, ×150

FIGURE 6.—POLISHED SECTION OF IRON FORMATION FROM THE FELCH DISTRICT, IN THE STAUROLITE ZONE

Hematite in granules has been metamorphosed to coarse specularite (white), in quartz matrix, ×150

PLATE 5.—PHOTOMICROGRAPHS OF OÖLITIC CHERT-HEMATITE IRON FORMATION FROM THREE ZONES OF METAMORPHISM

Illustrating progressive increase in grain size of quartz. Left, ordinary light; right, crossed nicols. Opaque mineral is hematite. All photographs ×30

FIGURE 1.—FROM WARNER MINE, IRON COUNTY; IN CHLORITE ZONE

FIGURE 2.—FROM GLOBE-CORNELL PIT, SOUTHERN DICKINSON COUNTY; IN UPPER PART OF BIOTITE ZONE

FIGURE 3.—FROM GROVELAND PIT, CENTRAL DICKINSON COUNTY; IN STAUROLITE ZONE

differences in metamorphism; most commonly, but not invariably, clinozoisite occurs as alteration of plagioclase, and epidote occurs in the alteration of groundmass material. Albite may be present as groundmass material or as a secondary product after primary labradorite. No porphyroblasts were observed.

Where present in the groundmass, the albite forms an obscure limpid background for other secondary minerals. Individual grains cannot be readily distinguished and twinning is rarely evident. Where pseudomorphic after labradorite, optically continuous albite preserves the general outline of the original grains, although other secondary products invariably are present. Unlike the pseudomorphic replacement of pyroxene by secondary hornblende, in which pyroxene cores are not uncommonly preserved, very few slides examined showed labradorite only partly replaced; in virtually all cases, the alteration to albite is complete. This secondary albite shows albite twinning, with a spacing of lamellae similar to that typically found in more calcic types. Extinction angles (in the zone normal to 010) are typically on the order of 10°–15°, which agree with the index determinations in establishing the composition as albite.

Calcite, sericite, and quartz are common constituents though rarely of major importance. "Leucoxene", as a fine-grained white-reflecting opaque substance, is present in almost all slides, generally as small grains in the groundmass. In the diabases that contained primary magnetite-ilmenite, examination in reflected light very commonly shows the original magnetite striped with white-reflecting leucoxene bands that have replaced the primary ilmenite. Sphene is not a common mineral, at least in readily identifiable form (quite possibly the "leucoxene" actually is sphene), but a specimen of greenstone from the Mastodon belt, in sec. 9, T. 41 N., R. 32 W. about 10 miles southeast from Crystal Falls, shows sphene in numerous scattered plates, and some that occurs in a fashion similar to leucoxene stripes in magnetite. Magnetite clearly is a relict primary mineral in the associations described, but a more common occurrence is as small crystals in the original tuffs and lavas, where it may be present in sufficient quantity to yield large magnetic anomalies. Whether this magnetite is of primary or metamorphic origin is not known.

The presence of albite in all the greenstones in the region, and the abundance in some, suggested the possibility that these rocks were actually spilites and that the albite was not of metamorphic origin. To test this possibility, a number of samples were analyzed for Ca and Na. The results, which are listed in Table 5, show that the rocks originally were basaltic in composition and that the modal feldspar (albite) is not a primary mineral. The results indicate that the bulk composition of the rock has remained constant in the lower zones of metamorphism (except for addition of CO_2 and H_2O) but that both Ca and Na may locally be increased or decreased.

BIOTITE ZONE: In outward appearance, most of the basic igneous rocks within the lower part of the biotite zones are indistinguishable from those in the chlorite zone, and even in thin section the differences are not marked. However, a green or greenish-brown biotite is present in some varieties and locally is abundant; such biotite-bearing rock, both intrusive and extrusive, is exposed along the Menominee River about 6 miles northwest of Iron Mountain.

Near the upper limit of the biotite zone, the mineralogic differences are much more marked, and the rock assumes the appearance of an amphibolite rather than a greenstone. This is due chiefly to the decrease or disappearance of chlorite and to the change in the nature of the hornblende, which is black rather than greenish to the naked eye. In thin section, the rock is different from the greenstone of the chlorite zone, both in mineralogy and texture. The most striking difference is in the increase in grain size of the metamorphic minerals. The hornblende forms clearer plates and is pleochroic: X—yellowish green; Y—green; Z—bluish green; the plagioclase verges toward oligoclase (rather commonly with the optic angle near 90° so that some determinations appear to yield a positive, others a negative sign). Epidote is abundant as distinct grains, many of which show clearly defined crystal outlines; clinozoisite is less common. Instead of opaque "leucoxene", the titania is held as sphene in granular aggregates. Original textures are preserved in many of the rocks, but in some it may be obscured by porphyroblastic growth of

TABLE 5.—CA AND NA CONTENT OF SOME METAMORPHOSED BASIC IGNEOUS ROCKS FROM THE CHLORITE ZONE IN NORTHERN MICHIGAN

Analyses, by rapid methods, made by Joseph M. Dowd, U. S. Geological Survey. Average basalt and spilite given for comparison.

No.	Weight per cent		Molecular proportions		Molecular ratios CaO:Na_2O
	CaO	Na_2O	CaO	Na_2O	
1	10.8	2.2	.193	.035	5.5
2	7.1	2.8	.127	.045	2.8
3	11.3	1.9	.202	.031	6.5
4	8.7	3.0	.155	.048	3.2
5	7.3	3.2	.130	.052	2.5
6	7.8	2.6	.139	.042	3.3
7	5.4	3.8	.096	.061	1.6
8	9.5	2.3	.170	.037	4.6
9	3.1	2.8	.055	.045	1.2
10	9.4	2.6	.168	.042	4.0
11	8.9	2.6	.159	.042	3.8
12	10.4	2.4	.186	.039	4.8
13	5.1	3.4	.091	.055	1.7
14	8.8	2.7	.157	.044	3.6
15	7.4	0.9	.132	.015	8.8
16	8.4	2.4	.150	.039	3.8
17	8.4	3.1	.150	.050	3.0
18	8.0	2.7	.143	.044	3.2
19	5.6	3.9	.100	.063	1.6
20	8.9	2.2	.159	.035	4.5
Average (1–20)	8.0	2.7	.143	.044	3.25
21	8.9	3.2	.159	.052	3.06
22	6.89	4.93	.123	.080	1.54

No.	Field description	Location
1	Greenstone	Sec. 20, T. 43 N., R. 32 W.
2	Greenstone (Pre-Huronian)	Sec. 19, T. 45 N., R. 1 E. (Wis.)
3	Metadiabase	Sec. 13, T. 43 N., R. 35 W.
4	Greenstone, massive	Sec. 11, T. 43 N., R. 33 W.
5	Greenstone, amydaloidal	Sec. 23, T. 42 N., R. 34 W.
6	Metadiabase	Sec. 24, T. 43 N., R. 33 W.
7	Greenstone	Sec. 17, T. 42 N., R. 35 W.
8	Greenstone, ellipsoidal	Sec. 29, T. 42 N., R. 33 W.
9	Greenstone	Sec. 17, T. 43 N., R. 35 W.
10	Greenstone	Sec. 17, T. 43 N., R. 35 W.

TABLE 5.—*Continued*

No.	Field description	Location
11	Porphyritic greenstone	Sec. 25, T. 43 N., R. 34 W.
12	Porphyritic greenstone	Sec. 20, T. 43 N., R. 33 W.
13	Greenstone	Sec. 20, T. 42 N., R. 35 W.
14	Greenstone (agglomerate)	Sec. 21, T. 42 N., R. 35 W.
15	Greenstone, ellipsoidal	Sec. 8, T. 43 N., R. 33 W.
16	Greenstone schistose	Sec. 9, T. 43 N., R. 31 W.
17	Metagabbro	Sec. 9, T. 43 N., R. 31 W.
18	Metagabbro	Sec. 17, T. 43 N., R. 31 W.
19	Metagabbro	Sec. 31, T. 44 N., R. 31 W.
20	Greenstone	Sec. 18, T. 43 N., R. 31 W.
21	Average basalt, as quoted by Tyrrell (1929, p. 131) from Daly	
22	Average spilite, as quoted by Turner and Verhoogen (1951, p. 204) from Sundius	

the hornblende. The metamorphosed basic igneous rock in the upper part of the biotite zone is properly classed as epidote amphibolite; such rock is widely exposed in the northern part of the Kiernan quadrangle, in T. 44 N., R. 31 W.

GARNET ZONE: The basic igneous rocks within the garnet zone are very much like those in the upper part of the biotite zone. They are epidote amphibolites. A typical example is from a dike cutting the lower Huronian quartzite in sec. 20, T. 41 N., R. 30 W., in Dickinson County, about 8 miles north of Iron Mountain. This rock (Pl. 4, fig. 3) shows the original texture but the only original mineral appears to be magnetite, which is preserved as skeletal crystals. The hornblende is classed as "blue-green"; it is strongly pleochroic with X—pale yellow, Y—emerald green, Z—greenish blue. The plagioclase, which retains the general outlines of original grains, is sodic oligoclase (about An_{18}); it shows wide-spaced albite twinning lamellae. Brown biotite is fairly abundant, as is epidote and quartz. Muscovite, apatite, and sphene are accessories. In outcrop, the rock is black, massive, and unfoliated.

Metavolcanic rock of the Hemlock greenstone is well exposed along the Fence River in

northeastern Iron County, especially in sec. 21, T. 45 N., R. 31 W., within the garnet zone. The rock is massive amphibolite showing strong preferred orientation of hornblende. It is composed of blue-green hornblende, brown biotite, epidote, untwinned sodic oligoclase, quartz, scattered patchy carbonate, and magnetite. The abundance of biotite and quartz in some of this rock suggests that it originally may have been an intermediate rather than a basic volcanic. Garnet is present in one or two slides examined, but the containing rock may be of interbedded sedimentary origin, rather than volcanic. Chloritoid was reported by Clements and Smyth (1899, p. 442–445) from sec. 10, T. 44 N., R. 31 W., a short distance south of the area described, but examination of all outcrops in that section and study of dozens of thin sections fails to confirm this occurrence (J. E. Gair and K. L. Wier, personal communication).

STAUROLITE ZONE: Metamorphosed basic intrusive rock within what is believed to be the staurolite zone is exposed at many places. It is now amphibolite. Dozens of such dikes cutting granite are exposed along Highway M-95 between Republic and Humboldt. Sills are numerous in the Felch district—a large one is exposed within the village of Felch.

Differences between the amphibolite of the staurolite zone and the epidote amphibolite of the main part of the garnet zone are not marked in outcrop but are clearly evident in thin section. The most obvious differences are the absence of epidote (except as a retrograde product) and the increase in anorthite content of the plagioclase. This transition from epidote amphibolite probably occurs within the upper part of the garnet zone. Texturally, most of the specimens studied are dominated by large hornblende plates, generally with irregular outline, which are set in a matrix of equigranular plagioclase and quartz with some biotite and sphene. The plagioclase typically is well twinned and of a composition varying from An_{35} to An_{45}. The change from the sodic oligoclase of the garnet zone to intermediate or calcic andesine is abrupt and doubtless is related to the absence of epidote in the higher zone of metamorphism; in the sections studied, no plagioclase was found with a composition in the range An_{30}–An_{30}. The hornblende plates are typically larger than associated grains; green is the dominant color, with strong pleochroism (X—yellowish; Y—green; Z—green, faintly bluish). Biotite is common as clear plates ranging in color from yellowish brown to reddish brown, the latter more common in the higher part of the zone. Other constituents of the rock are quartz, muscovite, sphene, and magnetite. Amphibolite from the staurolite zone in western Marquette County, between Republic and Humboldt, is illustrated in Figure 4 of Plate 4.

Both intrusive and extrusive rocks of the basic igneous group are present on the west end of the Marquette range, but too few specimens were taken to provide an adequate description. The rocks vary more in composition than those elsewhere. Specimens available show some to be abnormally rich in hornblende and one is very high in apatite. Nevertheless, the general aspects of the mineralogy are in harmony with those established elsewhere, with one major exception. Dark-colored chloritic rocks, apparently sills, occur at the Spurr mine and adjacent properties on the north side of Lake Michigamme. Some of this rock contains large, well-formed partly chloritized garnets, up to an inch in diameter, in a matrix of chlorite. The chlorite probably is of retrograde origin.

SILLIMANITE ZONE: Few specimens of basic igneous rock from the sillimanite zone have been studied. Most are similar to the amphibolite from the staurolite zone—chiefly green hornblende and andesine. However, some specimens from the Peavy node in southeastern Iron County contain brownish hornblende, and some contain abundant pyroxene adjacent to gabbroic intrusive bodies (R. W. Bayley, personal communication). The pyroxene-bearing rock is granoblastic, with irregular anhedra of nearly colorless diopside and scarce hypersthene in a matrix of andesine grains. Hornblende occurs as discrete grains or as replacements of the pyroxenes, and the rock apparently is a hornfels modified by regional metamorphism.

Basic intrusives are well exposed at the town of Republic within a sillimanite zone. Green hornblende and andesine are the major constituents of the few specimens studied, but the

rocks have been changed extensively by retrograde metamorphism and it is possible that some features—the color of the hornblende, for example—are now significantly different from those produced at the peak of the progressive metamorphism.

Iron Formation

General.—Metamorphism of the iron formation rocks is a more complex problem than that of the rock groups thus far described, principally because of the variety in primary lithologies and because of the difficulty in obtaining unoxidized materials.

The writer believes that the iron-rich rocks in their unaltered condition can be divided on the basis of the dominant iron mineral into four major facies, namely: sulfide, carbonate, silicate, and oxide (James, 1954). The sulfide facies, which is rare in the middle Huronian strata but more abundant in the upper Huronian, is a black carbonaceous shale or slate that contains as much as 40 per cent of very finely disseminated pyrite. The carbonate facies, a dominant rock type in the Marquette and Iron River-Crystal Falls districts, typically is laminated or thin-bedded chert and iron-rich carbonate. The composition of the carbonate falls within the ranges $FeCO_3$, 70–90 per cent; $MgCO_3$; 5–15 per cent; $CaCO_3$; 1–10 per cent; $MnCO_3$; 0–10 per cent. The silicate facies is minor but widespread; it is a greenish rock that consists of an iron-rich silicate plus variable amounts of magnetite, iron carbonate, and chert. In the lowest-grade zones of metamorphism in Michigan, the silicate layers consist of minnesotaite, stilpnomelane, or an iron chlorite The oxide facies is comparable in abundance to the carbonate facies. It is represented by two primary types, one in which magnetite is dominant and one in which hematite is dominant. Both are thin-bedded rocks with interlayered chert.

Assuming that pyrite, siderite, greenalite, chlorite, hematite, and magnetite are wholly or in part of primary origin, new phases are few in many types of iron formation; much of the metamorphic energy has been expended in coarsening of grain size of the original minerals. Minerals of metamorphic origin are grunerite, epidote, garnet, hornblende, pyroxene, and some magnetite. Fayalite, common on the Mesabi range within the metamorphic aureole of the Duluth gabbro, is not present. Stilpnomelane and minnesotaite in their present form are clearly metamorphic in some rocks but could have developed from pre-existing silicate material at very low metamorphic or even premetamorphic levels. The same may be true of the present chlorite found in some types of iron formation, as mineralogic changes accomplished during the diagenesis-lithification period are perhaps indistinguishable from those accomplished during the period of active metamorphism.

Simple increase in grain size is an obvious effect of metamorphic activity on the iron-formation rocks, and in some it may be the only change. It is most readily observed in the original chert layers and has been noted by previous workers in the region; Van Hise and Bayley (1897, p. 372-373) stated:

> "The quartz grains in the extreme west end of the district have diameters averaging from 0.10 to 0.15 mm., and in the southwest arm they average about 0.20 to 0.40 mm., and run as high as 1.0 mm. It will be seen that the size of the grains is many times greater than in the Ishpeming-Negaunee area, where the average diameters vary from less than 0.01 mm. to 0.03 mm."

(*Note:* the "southwest arm" is the western part of the Republic district.) The quartz grain size can provide an accurate index of metamorphic grade, but associated materials have a pronounced effect—a chert layer containing dispersed silicate, for example, will not be as coarse-grained as an adjacent layer of more nearly pure silica—and in all metamorphic zones the quartz may locally be much coarser or more irregular in grain size than in the rock as a whole. Other difficulties are involved in obtaining a strictly valid parameter, particularly in rock from the lowest metamorphic zone. In this zone, where grain size is 0.01–0.05 mm, grain boundaries are exceedingly irregular, and a single-line traverse may cut the same grain more than once; dividing the length of the traverse by the number of intersections will tend to yield a value lower than the true mean diameter. In some specimens the quartz shows noticeable dimensional orientation, which is only partly overcome in single thin sections by measurement along and across the pre-

ferred direction. The appearance of the quartz in three zones of metamorphism is shown in Plate 5. The rock is oölitic iron formation, consisting of metachert and hematite. The increase in grain size of the quartz is shown by comparison of the successive crossed-nicol views.

Some generalizations regarding metamorphism of iron-formation rocks are presented in Table 6.

Iron formation in the chlorite and biotite zones.—Mineralogically the iron formation in the chlorite zone resembles that in the biotite zone. Minnesotaite and stilpnomelane are the characteristic silicates; greenalite, which is abundant on the Mesabi range of Minnesota, is not present in the principal iron formations in Michigan, although it is a minor constituent of pyritic slate in the Iron River district (James, 1951). Whether the minnesotaite and stilpnomelane are sedimentary or metamorphic in origin is a moot point. Gruner (1946) considers them to be primary along with greenalite in the Mesabi range rocks. Textural relationships indicate that both the minnesotaite and stilpnomelane are at least in part of secondary origin, but the observed relationships might have developed by crystal growth during diagenesis and lithification. Tyler (1949) concludes that these minerals, as well as grunerite, are formed by metamorphic reactions, in part between carbonate and chert and in part between greenalite and chert. However, laminae of virtually pure silicate (stilpnomelane or minnesotaite or both) are commonly interbedded with layers of mixed chert and carbonate that show no sign of mutual reaction. These low-grade silicates probably are derived chiefly from preexisting silicate material of similar composition, although locally, as for example adjacent to a diabase sill, they may be produced by a carbonate-chert reaction. Grunerite, the iron amphibole, is in large part due to the carbonate-chert reaction, but this mineral is not present in the lower zones of metamorphism. (In the early U. S. Geological Survey monographs much silicate in the lower zones of metamorphism, now known to be minnesotaite or stilpnomelane, was incorrectly identified as grunerite).

The silicate iron formation that was in part of detrital origin (clastic grains are recognizable) contains the most diverse products of any of the iron-rich rocks. It is not clear which of the present minerals are primary; the chert and carbonate probably can be so classed. Magnetite, stilpnomelane, chlorite (aphrosiderite or thuringite) probably are secondary, and the biotite—a dark-green or greenish-brown variety—almost certainly is secondary. This last mineral is present in the silicate-rich "magnetic ironstone" of the Crystal Falls district, an area within the chlorite zone.

Fineness of grain is characteristic of most iron-formation constituents in the lower zones of metamorphism. The grain size of the quartz typically is about 0.03 mm in the chlorite zone, with an estimated maximum of 0.05 mm. Values of 0.05–0.10 mm characterize the biotite zone. There are some quantitatively unimportant exceptions to the general fine grain in the lower zones; for example, magnetite and siderite commonly occur as coarse-grained replacements of hematite oöliths or silicate granules as a result of diagenesis. Pyrite also occurs locally as atypical coarse grains.

Garnet and staurolite zones.—Iron formation at the intermediate level of metamorphism is exposed at four major localities within the area of Plate 1, namely: the western part of the Marquette range, the Felch district of central Dickinson County, the Fence River area of northeastern Iron County, and the southwestern part of the Florence district in Wisconsin.

The west Marquette rocks comprise a variety of principal lithologic types; the major ones are:

Magnetite-quartz
Magnetite-grunerite-quartz
Grunerite-quartz (garnet)
Specularite-quartz.

Garnet, biotite, muscovite, and a bluish-green hornblende are minor constituents in most, and a small amount of carbonate is present in some. Chlorite commonly is abundant but is clearly of retrograde origin. Lack of stratigraphic data hinders direct comparison with the more weakly metamorphosed strata of the eastern Marquette area except in a general way, although the specularite-quartz rock doubtless is the equivalent of the "jaspilite" of the same composition but finer grain size. The origin of the magnetite and grunerite rocks

TABLE 6.—CHART SHOWING TENTATIVE CONCLUSIONS REGARDING METAMORPHISM OF PRINCIPAL TYPES OF IRON FORMATION

Major constituents shown in upper-case letters

Sedimentary			Metamorphic		
Facies		Composition*	Low Grade†	Intermediate**	High grade††
Sulfide		Ferrous sulfide Organic carbon "Clay"	PYRITE CARBON (amorphous) QUARTZ Sericite	PYRITE GRAPHITE QUARTZ Micas Garnet (rare)	PYRITE GRAPHITE Pyrrhotite (?) Micas-garnet
Carbonate		Carbonate Chert Greenalite	CARBONATE QUARTZ Stilpnomelane Minnesotaite	GRUNERITE QUARTZ Magnetite Carbonate	GRUNERITE QUARTZ Magnetite Pyroxene
Silicate	Non-clastic	Greenalite Chert Carbonate Magnetite	MINNESOTAITE STILPNOMELANE QUARTZ CARBONATE Magnetite	GRUNERITE QUARTZ Magnetite	GRUNERITE QUARTZ Magnetite Pyroxene
	Partly clastic	Iron-rich clay Chert Carbonate Magnetite(?)	CHLORITE STILPNOMELANE QUARTZ CARBONATE MAGNETITE Biotite	GRUNERITE QUARTZ MAGNETITE EPIDOTE GARNET Carbonate Mica	GRUNERITE QUARTZ MAGNETITE Garnet Hornblende Pyroxene
Oxide	Magnetite-banded	Magnetite Carbonate Greenalite Chert	MAGNETITE STILPNOMELANE MINNESOTAITE CARBONATE QUARTZ	MAGNETITE GRUNERITE QUARTZ Garnet	MAGNETITE GRUNERITE QUARTZ Pyroxene Garnet
	Hematite-banded	Ferric oxide Chert Magnetite Calcite	HEMATITE QUARTZ Magnetite Calcite	SPECULAR HEMATITE QUARTZ Magnetite Calcite	SPECULAR HEMATITE QUARTZ Magnetite Calcite
			less than 0.10 mm	0.1 to 0.20 mm	more than 0.20 mm
			Quartz grain size***		

* Inferred.
† Chlorite and biotite zones.
** Garnet and staurolite zones.
†† Sillimanite zone, essentially. Inferred for some rocks.
*** Diameter of typical grains in relatively pure layers of chert.

is not as obvious. Earlier workers, such as Van Hise and Bayley (1897) and Richarz (1927b), assumed that all were derived from original chert-carbonate iron formation. However, in some of the iron formation of the eastern Marquette the iron is in the form of magnetite or minnesotaite, and the metamorphic assemblages may well represent equivalents of such rock. The magnetite of the intermediate and higher zones commonly is assumed to be of secondary origin, but it is questionable whether this mineral is ever produced in abundance by metamorphism of iron formation. The available information is not sufficient to establish the relative amounts of magnetite in the various zones in the Michigan ranges, but it is a major constituent even in the lowest zones of metamorphism, and according to Gruner (1946) the highly metamorphosed east Mesabi range contains no more magnetite than do the central and western parts. He writes (p. 73):

> "Expressed another way, the changes in the iron minerals brought about by metamorphism on the East Mesabi range did not produce additional Fe_3O_4, but iron amphiboles, olivines, and pyroxenes. The chief reason was undoubtedly the unavailability of additional oxygen, particularly in the case of siderite, whose iron combined with chert to form silicates instead of forming magnetic oxide as it does when heated in a closed tube in the laboratory in the presence of a limited amount of air."

The metamorphism of the east Mesabi is due in large part to the Duluth gabbro and thus is not strictly comparable to that under discussion, but there seems no obvious reason why the siderite metamorphism should be appreciably different. As a tentative conclusion, then, the dominantly magnetitic rock of the garnet and staurolite zones is considered to represent original magnetite-rich iron formation, although local conditions might have permitted development of some magnetite from carbonate.

The grunerite-rich rocks such as those of the western Marquette probably are derived from both the carbonate and silicate facies of primary iron formation. The analyses listed in Table 7 indicate that either is appropriate as a precursor of the grunerite-quartz rock. The metamorphic destruction of carbonate and combination of the cations with silica is strictly comparable to the development of tremolite and diopside in metamorphosed limestone and dolomite and is properly referred to as silication, whereas the change from lower-grade silicates to grunerite is simply a transformation from one silicate structure to another.

TABLE 7.—ANALYSES OF GRUNERITE-QUARTZ ROCKS AS COMPARED WITH AVERAGE ANALYSES OF IRON FORMATION OF THE SILICATE AND CARBONATE FACIES IN LOWER ZONES OF METAMORPHISM

	A	B	C	D
SiO_2	46.94	49.70	50.7	35.9
Al_2O_3	0.66	1.35	0.4	1.0
Fe_2O_3	4.51	3.10	5.6	1.2
FeO	33.72	37.19	28.9	32.8
MgO	6.64	5.72	4.2	2.7
CaO	3.22	0.68	0.1*	1.1
Na_2O	0.16	tr.	none*	n.d.
K_2O	n.d.	n.d.	none*	n.d.
H_2O^-	0.67	1.40	0.6*	0.8
H_2O^+	—	—	5.2	
CO_2	2.79	—	5.1†	23.3
P_2O_5	0.07	0.12	none*	0.3
MnO	0.31	0.93	0.9*	0.9

A. Grunerite-quartz rock. Humboldt area, Marquette range; sec. 11, T. 47 N., R. 27 W. (Van Hise and Bayley, 1897, p. 338).

B. Grunerite-quartz rock. West of Humboldt, Marquette range; sec. 18, T. 47 N., R. 28 W. (Van Hise and Bayley, 1897, p. 338).

C. Silicate iron-formation (minnesotaite-rich). Mesabi range, average of 5 analyses quoted in James (1954, p. 271).

D. Carbonate iron-formation. Average of analyses A, C, D, E, F in James (1954, p. 253).

* Not determined on 3 of the 5 samples

† Not determined on one of the 5 samples

Iron formation within the staurolite zone is well exposed in a number of places in the Felch district of central Dickinson County. Two principal types are present: gray-banded iron formation that consists principally of quartz interlayered with magnetite, and oölitic iron formation that consists principally of specular hematite, magnetite, and quartz. Grunerite, garnet, hornblende, and micas are minor constituents of both types. The gray-banded rock forms the lower part of the iron-formation unit; it is exposed in sec. 5, T. 41 N., R. 30 W. and

has been drilled at many localities. The oölitic rock forms the upper part and is well exposed at the village of Felch and at the Groveland pit, 7 miles west of Felch (Pl. 5, fig. 3). Large plates of specularite, as much as an inch in length, are developed locally as porphyroblasts in some thick magnetite layers. The two rock types were derived from primary rocks of similar character except for the grunerite-rich parts of the lower unit, which probably are equivalent to original carbonate or carbonate-silicate layers.

The iron formation that is exposed along the Fence River in sec. 21, T. 45 N., R. 31 W. within the garnet zone in the northeastern Iron County is "lean" and in part clastic. The following mineral assemblages are represented:

(1) Quartz-magnetite-specularite (quartz in part clastic)
(2) Specularite-quartz (oölitic)
(3) Magnetite-epidote-quartz-biotite-muscovite
(4) Grunerite-garnet-magnetite.

Assemblage (1) probably represents a highly ferruginous siltstone or sandstone, assemblage (2) an original chert-hematite oölite. Assemblages (3) and (4) are the garnet-zone equivalents of a rock such as the magnetic ironstone of the chlorite zone in the Iron River-Crystal Falls district, which consists of magnetite, chert, chlorite, and carbonate in variable proportions. Clastic grains are recognizable in both. As seen in thin section a small amount of carbonate, cut by numerous blades of grunerite, is preserved in some of the Fence River rock, and in one slide stilpnomelane (a very dark ferric variety) is present. Chlorite and a bluish-green amphibole are common as retrograde products.

The iron formation from the area of moderate to high metamorphism in Florence County, Wisconsin, has been sampled in only a few places. Much of the rock is of the garnet-grunerite-magnetite type.

In general, the key mineral of the intermediate-intensity metamorphism of the iron-formation rocks is grunerite. The appearance of this mineral probably slightly precedes that of garnet in the argillaceous rocks. The composition and optical properties are presented by Richarz (1927a, 1927b, 1927c, 1932). It occurs as blades characteristically arranged in radiating groups, the forms of which quite commonly are preserved even where the rock is entirely altered to limonite. The local presence of stilpnomelane in the garnet zone is taken to indicate that its field of stability extends slightly beyond the biotite level, though the mineral may be retrograde in this association. Garnet, sporadically present in most iron formation and very abundant in some, apparently develops at about the same level as the garnet in argillaceous rocks. A blue-green amphibole is very common in the iron-formation rocks above the garnet isograd. In some it appears to be definitely a retrograde mineral, but elsewhere it appears to be product of the regional metamorphism. Similar material is described by Richarz (1930) from the east Mesabi and by Miles (1943) from grunerite rocks of western Australia. The analysis given by Richarz shows 21.72 per cent FeO and 7.92 per cent Fe_2O_3, and that by Miles 25.0 and 8.7. The mineral is more abundant in some layers than others and may represent original clay material.

Iron-rich carbonate is only locally preserved within the garnet zone and even there the paragenetic relationships indicate that it is in the process of alteration to grunerite. Within the staurolite zone, the only carbonate remaining—other than that occurring as cross-cutting veins—is calcite, which confirms the laboratory evidence on the relative stability of calcium-rich as compared with iron-rich types.

Sillimanite zone.—The only locality at which iron formation is believed to be in the sillimanite zone is the Republic district of southwestern Marquette County. In this area it is a thin-banded rock, dominantly of magnetite, grunerite, and quartz in the lower part, and a banded specularite-chert rock in the upper part. Both types are well exposed at the town of Republic and in the area to the northwest, but details of the mineralogy in many of the specimens are somewhat obscured because of widespread retrograde alteration. Oölitic structures are preserved locally in the specularite-chert rock despite the coarseness of mineral grains; derivation was from an original oxide iron formation little different in composition from the present rock. The hematite forms plates with pronounced preferred orientation parallel to the axial planes of the folds. The

northeastern Iron County, especially in sec. 21, T. 45 N., R. 31 W., within the garnet zone. The rock is massive amphibolite showing strong preferred orientation of hornblende. It is composed of blue-green hornblende, brown biotite, epidote, untwinned sodic oligoclase, quartz, scattered patchy carbonate, and magnetite. The abundance of biotite and quartz in some of this rock suggests that it originally may have been an intermediate rather than a basic volcanic. Garnet is present in one or two slides examined, but the containing rock may be of interbedded sedimentary origin, rather than volcanic. Chloritoid was reported by Clements and Smyth (1899, p. 442–445) from sec. 10, T. 44 N., R. 31 W., a short distance south of the area described, but examination of all outcrops in that section and study of dozens of thin sections fails to confirm this occurrence (J. E. Gair and K. L. Wier, personal communication).

STAUROLITE ZONE: Metamorphosed basic intrusive rock within what is believed to be the staurolite zone is exposed at many places. It is now amphibolite. Dozens of such dikes cutting granite are exposed along Highway M-95 between Republic and Humboldt. Sills are numerous in the Felch district—a large one is exposed within the village of Felch.

Differences between the amphibolite of the staurolite zone and the epidote amphibolite of the main part of the garnet zone are not marked in outcrop but are clearly evident in thin section. The most obvious differences are the absence of epidote (except as a retrograde product) and the increase in anorthite content of the plagioclase. This transition from epidote amphibolite probably occurs within the upper part of the garnet zone. Texturally, most of the specimens studied are dominated by large hornblende plates, generally with irregular outline, which are set in a matrix of equigranular plagioclase and quartz with some biotite and sphene. The plagioclase typically is well twinned and of a composition varying from An_{35} to An_{45}. The change from the sodic oligoclase of the garnet zone to intermediate or calcic andesine is abrupt and doubtless is related to the absence of epidote in the higher zone of metamorphism; in the sections studied, no plagioclase was found with a composition in the range An_{20}–An_{30}. The hornblende plates are typically larger than associated grains; green is the dominant color, with strong pleochroism (X—yellowish; Y—green; Z—green, faintly bluish). Biotite is common as clear plates ranging in color from yellowish brown to reddish brown, the latter more common in the higher part of the zone. Other constituents of the rock are quartz, muscovite, sphene, and magnetite. Amphibolite from the staurolite zone in western Marquette County, between Republic and Humboldt, is illustrated in Figure 4 of Plate 4.

Both intrusive and extrusive rocks of the basic igneous group are present on the west end of the Marquette range, but too few specimens were taken to provide an adequate description. The rocks vary more in composition than those elsewhere. Specimens available show some to be abnormally rich in hornblende and one is very high in apatite. Nevertheless, the general aspects of the mineralogy are in harmony with those established elsewhere, with one major exception. Dark-colored chloritic rocks, apparently sills, occur at the Spurr mine and adjacent properties on the north side of Lake Michigamme. Some of this rock contains large, well-formed partly chloritized garnets, up to an inch in diameter, in a matrix of chlorite. The chlorite probably is of retrograde origin.

SILLIMANITE ZONE: Few specimens of basic igneous rock from the sillimanite zone have been studied. Most are similar to the amphibolite from the staurolite zone—chiefly green hornblende and andesine. However, some specimens from the Peavy node in southeastern Iron County contain brownish hornblende, and some contain abundant pyroxene adjacent to gabbroic intrusive bodies (R. W. Bayley, personal communication). The pyroxene-bearing rock is granoblastic, with irregular anhedra of nearly colorless diopside and scarce hypersthene in a matrix of andesine grains. Hornblende occurs as discrete grains or as replacements of the pyroxenes, and the rock apparently is a hornfels modified by regional metamorphism.

Basic intrusives are well exposed at the town of Republic within a sillimanite zone. Green hornblende and andesine are the major constituents of the few specimens studied, but the

rocks have been changed extensively by retrograde metamorphism and it is possible that some features—the color of the hornblende, for example—are now significantly different from those produced at the peak of the progressive metamorphism.

Iron Formation

General.—Metamorphism of the iron formation rocks is a more complex problem than that of the rock groups thus far described, principally because of the variety in primary lithologies and because of the difficulty in obtaining unoxidized materials.

The writer believes that the iron-rich rocks in their unaltered condition can be divided on the basis of the dominant iron mineral into four major facies, namely: sulfide, carbonate, silicate, and oxide (James, 1954). The sulfide facies, which is rare in the middle Huronian strata but more abundant in the upper Huronian, is a black carbonaceous shale or slate that contains as much as 40 per cent of very finely disseminated pyrite. The carbonate facies, a dominant rock type in the Marquette and Iron River-Crystal Falls districts, typically is laminated or thin-bedded chert and iron-rich carbonate. The composition of the carbonate falls within the ranges $FeCO_3$, 70–90 per cent; $MgCO_3$; 5–15 per cent; $CaCO_3$; 1–10 per cent; $MnCO_3$; 0–10 per cent. The silicate facies is minor but widespread; it is a greenish rock that consists of an iron-rich silicate plus variable amounts of magnetite, iron carbonate, and chert. In the lowest-grade zones of metamorphism in Michigan, the silicate layers consist of minnesotaite, stilpnomelane, or an iron chlorite. The oxide facies is comparable in abundance to the carbonate facies. It is represented by two primary types, one in which magnetite is dominant and one in which hematite is dominant. Both are thin-bedded rocks with interlayered chert.

Assuming that pyrite, siderite, greenalite, chlorite, hematite, and magnetite are wholly or in part of primary origin, new phases are few in many types of iron formation; much of the metamorphic energy has been expended in coarsening of grain size of the original minerals. Minerals of metamorphic origin are grunerite, epidote, garnet, hornblende, pyroxene, and some magnetite. Fayalite, common on the Mesabi range within the metamorphic aureole of the Duluth gabbro, is not present. Stilpnomelane and minnesotaite in their present form are clearly metamorphic in some rocks but could have developed from pre-existing silicate material at very low metamorphic or even pre-metamorphic levels. The same may be true of the present chlorite found in some types of iron formation, as mineralogic changes accomplished during the diagenesis-lithification period are perhaps indistinguishable from those accomplished during the period of active metamorphism.

Simple increase in grain size is an obvious effect of metamorphic activity on the iron-formation rocks, and in some it may be the only change. It is most readily observed in the original chert layers and has been noted by previous workers in the region; Van Hise and Bayley (1897, p. 372-373) stated:

> "The quartz grains in the extreme west end of the district have diameters averaging from 0.10 to 0.15 mm., and in the southwest arm they average about 0.20 to 0.40 mm., and run as high as 1.0 mm. It will be seen that the size of the grains is many times greater than in the Ishpeming-Negaunee area, where the average diameters vary from less than 0.01 mm. to 0.03 mm."

(*Note:* the "southwest arm" is the western part of the Republic district.) The quartz grain size can provide an accurate index of metamorphic grade, but associated materials have a pronounced effect—a chert layer containing dispersed silicate, for example, will not be as coarse-grained as an adjacent layer of more nearly pure silica—and in all metamorphic zones the quartz may locally be much coarser or more irregular in grain size than in the rock as a whole. Other difficulties are involved in obtaining a strictly valid parameter, particularly in rock from the lowest metamorphic zone. In this zone, where grain size is 0.01–0.05 mm, grain boundaries are exceedingly irregular, and a single-line traverse may cut the same grain more than once; dividing the length of the traverse by the number of intersections will tend to yield a value lower than the true mean diameter. In some specimens the quartz shows noticeable dimensional orientation, which is only partly overcome in single thin sections by measurement along and across the pre-

ferred direction. The appearance of the quartz in three zones of metamorphism is shown in Plate 5. The rock is oölitic iron formation, consisting of metachert and hematite. The increase in grain size of the quartz is shown by comparison of the successive crossed-nicol views.

Some generalizations regarding metamorphism of iron-formation rocks are presented in Table 6.

Iron formation in the chlorite and biotite zones.—Mineralogically the iron formation in the chlorite zone resembles that in the biotite zone. Minnesotaite and stilpnomelane are the characteristic silicates; greenalite, which is abundant on the Mesabi range of Minnesota, is not present in the principal iron formations in Michigan, although it is a minor constituent of pyritic slate in the Iron River district (James, 1951). Whether the minnesotaite and stilpnomelane are sedimentary or metamorphic in origin is a moot point. Gruner (1946) considers them to be primary along with greenalite in the Mesabi range rocks. Textural relationships indicate that both the minnesotaite and stilpnomelane are at least in part of secondary origin, but the observed relationships might have developed by crystal growth during diagenesis and lithification. Tyler (1949) concludes that these minerals, as well as grunerite, are formed by metamorphic reactions, in part between carbonate and chert and in part between greenalite and chert. However, laminae of virtually pure silicate (stilpnomelane or minnesotaite or both) are commonly interbedded with layers of mixed chert and carbonate that show no sign of mutual reaction. These low-grade silicates probably are derived chiefly from preexisting silicate material of similar composition, although locally, as for example adjacent to a diabase sill, they may be produced by a carbonate-chert reaction. Grunerite, the iron amphibole, is in large part due to the carbonate-chert reaction, but this mineral is not present in the lower zones of metamorphism. (In the early U. S. Geological Survey monographs much silicate in the lower zones of metamorphism, now known to be minnesotaite or stilpnomelane, was incorrectly identified as grunerite).

The silicate iron formation that was in part of detrital origin (clastic grains are recognizable) contains the most diverse products of any of the iron-rich rocks. It is not clear which of the present minerals are primary; the chert and carbonate probably can be so classed. Magnetite, stilpnomelane, chlorite (aphrosiderite or thuringite) probably are secondary, and the biotite—a dark-green or greenish-brown variety—almost certainly is secondary. This last mineral is present in the silicate-rich "magnetic ironstone" of the Crystal Falls district, an area within the chlorite zone.

Fineness of grain is characteristic of most iron-formation constituents in the lower zones of metamorphism. The grain size of the quartz typically is about 0.03 mm in the chlorite zone, with an estimated maximum of 0.05 mm. Values of 0.05–0.10 mm characterize the biotite zone. There are some quantitatively unimportant exceptions to the general fine grain in the lower zones; for example, magnetite and siderite commonly occur as coarse-grained replacements of hematite oöliths or silicate granules as a result of diagenesis. Pyrite also occurs locally as atypical coarse grains.

Garnet and staurolite zones.—Iron formation at the intermediate level of metamorphism is exposed at four major localities within the area of Plate 1, namely: the western part of the Marquette range, the Felch district of central Dickinson County, the Fence River area of northeastern Iron County, and the southwestern part of the Florence district in Wisconsin.

The west Marquette rocks comprise a variety of principal lithologic types; the major ones are:

Magnetite-quartz
Magnetite-grunerite-quartz
Grunerite-quartz (garnet)
Specularite-quartz.

Garnet, biotite, muscovite, and a bluish-green hornblende are minor constituents in most, and a small amount of carbonate is present in some. Chlorite commonly is abundant but is clearly of retrograde origin. Lack of stratigraphic data hinders direct comparison with the more weakly metamorphosed strata of the eastern Marquette area except in a general way, although the specularite-quartz rock doubtless is the equivalent of the "jaspilite" of the same composition but finer grain size. The origin of the magnetite and grunerite rocks

TABLE 6.—CHART SHOWING TENTATIVE CONCLUSIONS REGARDING METAMORPHISM OF PRINCIPAL TYPES OF IRON FORMATION

Major constituents shown in upper-case letters

Sedimentary			Metamorphic		
Facies		Composition*	Low Grade†	Intermediate**	High grade††
Sulfide		Ferrous sulfide Organic carbon "Clay"	PYRITE CARBON (amorphous) QUARTZ Sericite	PYRITE GRAPHITE QUARTZ Micas Garnet (rare)	PYRITE GRAPHITE Pyrrhotite (?) Micas-garnet
Carbonate		Carbonate Chert Greenalite	CARBONATE QUARTZ Stilpnomelane Minnesotaite	GRUNERITE QUARTZ Magnetite Carbonate	GRUNERITE QUARTZ Magnetite Pyroxene
Silicate	Non-clastic	Greenalite Chert Carbonate Magnetite	MINNESOTAITE STILPNOMELANE QUARTZ CARBONATE Magnetite	GRUNERITE QUARTZ Magnetite	GRUNERITE QUARTZ Magnetite Pyroxene
	Partly clastic	Iron-rich clay Chert Carbonate Magnetite(?)	CHLORITE STILPNOMELANE QUARTZ CARBONATE MAGNETITE Biotite	GRUNERITE QUARTZ MAGNETITE EPIDOTE GARNET Carbonate Mica	GRUNERITE QUARTZ MAGNETITE Garnet Hornblende Pyroxene
Oxide	Magnetite-banded	Magnetite Carbonate Greenalite Chert	MAGNETITE STILPNOMELANE MINNESOTAITE CARBONATE QUARTZ	MAGNETITE GRUNERITE QUARTZ Garnet	MAGNETITE GRUNERITE QUARTZ Pyroxene Garnet
	Hematite-banded	Ferric oxide Chert Magnetite Calcite	HEMATITE QUARTZ Magnetite Calcite	SPECULAR HEMATITE QUARTZ Magnetite Calcite	SPECULAR HEMATITE QUARTZ Magnetite Calcite
			less than 0.10 mm	0.1 to 0.20 mm	more than 0.20 mm
			Quartz grain size***		

* Inferred.

† Chlorite and biotite zones.

** Garnet and staurolite zones.

†† Sillimanite zone, essentially. Inferred for some rocks.

*** Diameter of typical grains in relatively pure layers of chert.

is not as obvious. Earlier workers, such as Van Hise and Bayley (1897) and Richarz (1927b), assumed that all were derived from original chert-carbonate iron formation. However, in some of the iron formation of the eastern Marquette the iron is in the form of magnetite or minnesotaite, and the metamorphic assemblages may well represent equivalents of such rock. The magnetite of the intermediate and higher zones commonly is assumed to be of secondary origin, but it is questionable whether this mineral is ever produced in abundance by metamorphism ot iron formation. The available information is not sufficient to establish the relative amounts of magnetite in the various zones in the Michigan ranges, but it is a major constituent even in the lowest zones of metamorphism, and according to Gruner (1946) the highly metamorphosed east Mesabi range contains no more magnetite than do the central and western parts. He writes (p. 73):

> "Expressed another way, the changes in the iron minerals brought about by metamorphism on the East Mesabi range did not produce additional Fe_3O_4, but iron amphiboles, olivines, and pyroxenes. The chief reason was undoubtedly the unavailability of additional oxygen, particularly in the case of siderite, whose iron combined with chert to form silicates instead of forming magnetic oxide as it does when heated in a closed tube in the laboratory in the presence of a limited amount of air."

The metamorphism of the east Mesabi is due in large part to the Duluth gabbro and thus is not strictly comparable to that under discussion, but there seems no obvious reason why the siderite metamorphism should be appreciably different. As a tentative conclusion, then, the dominantly magnetitic rock of the garnet and staurolite zones is considered to represent original magnetite-rich iron formation, although local conditions might have permitted development of some magnetite from carbonate.

The grunerite-rich rocks such as those of the western Marquette probably are derived from both the carbonate and silicate facies of primary iron formation. The analyses listed in Table 7 indicate that either is appropriate as a precursor of the grunerite-quartz rock. The metamorphic destruction of carbonate and combination of the cations with silica is strictly comparable to the development of tremolite and diopside in metamorphosed limestone and dolomite and is properly referred to as silication, whereas the change from lower-grade silicates to grunerite is simply a transformation from one silicate structure to another.

TABLE 7.—ANALYSES OF GRUNERITE-QUARTZ ROCKS AS COMPARED WITH AVERAGE ANALYSES OF IRON FORMATION OF THE SILICATE AND CARBONATE FACIES IN LOWER ZONES OF METAMORPHISM

	A	B	C	D
SiO_2	46.94	49.70	50.7	35.9
Al_2O_3	0.66	1.35	0.4	1.0
Fe_2O_3	4.51	3.10	5.6	1.2
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CO_2	2.79	—	5.1†	23.3
P_2O_5	0.07	0.12	none*	0.3
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A. Grunerite-quartz rock. Humboldt area, Marquette range; sec. 11, T. 47 N., R. 27 W. (Van Hise and Bayley, 1897, p. 338).

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abundance of hematite in this highest zone of metamorphism contradicts the common assertion that hematite gives way to magnetite under high metamorphic intensity. (*Cf.* Harker, 1950, p. 237.)

Significance of metamorphic zones to economic aspects of iron formation.—The principal ore deposits of the region are the "soft ores", which are masses of yellow and red iron oxides produced in the iron formation by post-metamorphic oxidation of carbonate and silicates and removal or replacement of silica. For the most part, this material is "direct-shipping". The hard ores of the Marquette district, which form the second class of direct-shipping ores, are deposits of crystalline hematite that lie at the top of the Negaunee iron formation or at the base of the overlying Goodrich quartzite; they are less important than the soft ores of the region, though they do constitute nearly 15 per cent of the Marquette shipments to date The hard ores, whatever their origin (pre-upper Huronian laterite, sedimentary, or hydrothermal), are pre-metamorphic, evident from the fact that the grain size of the hematite varies directly with degree of metamorphism.

The low-grade ores of the area are being investigated by mining companies, though as yet production from this source is slight. On the basis of iron content, much or all of the iron formation of the region is a potential low-grade ore, but at the present time metallurgical problems limit the material that can be utilized to two types: (1) Oxidized iron formation that can be "beneficiated" to increase the iron content—in practice, this essentially means removal of silica. The beneficiation commonly consists of grinding to coarse-screen sizes and separation of iron-rich fractions by heavy-media techniques. Only a small fraction of the oxidized iron-formation of the region appears amenable to such treatment, and few guides other than empirical tests aid in classifying of rock as suitable or unsuitable. (2) Metamorphic iron formation, or taconite, the development of which is probably the major accomplishment of the past 50 years by the Lake Superior mining industry. This material is a hard tough crystalline rock, totally different from the soft porous oxidized iron formation used for "beneficiation". It must fill several specifications, the two most important of which are as follows:

(1) The iron must be principally in the form of magnetite or specularite. This restricts the suitable material to iron formation of the oxide facies.
(2) The grain size must be large enough to permit separation of individual grains by grinding to economically feasible screen sizes—200-mesh or larger.

With this brief statement of the types of ore as background, the significance of the metamorphic zones to the problems or iron-ore distribution can be discussed. The hard ore deposits are pre-metamorphic; their distribution therefore cannot (and does not) have any significance with respect to the metamorphism. The soft ores, which constitute the great bulk of the shipments to date, are postmetamorphic. Figure 3 is a sketch map of northern Michigan that shows the output through 1950 by townships (data tabulated from Lake Superior Iron Ores, 1952). The virtual limitation of major production to the low-grade zones is striking. (*See* Table 8.)

The distribution of areas under active consideration or development as sources of low-grade concentrating ore ("taconite") also shows striking correlation with the metamorphic pattern, but it is a correlation that is the reverse of that for the soft-ores. One—Republic—is within the sillimanite zone; three—Humboldt, Groveland, and Felch—are within the staurolite zone; and one—Banner—is in an undetermined position at some level above the garnet isograd. None lies within lower zones of metamorphism.

The principal factor involved in these two correlations probably is the variation of grain size with metamorphic grade. For the concentrating ore the relationship can be ap-

FIGURE 3.—SKETCH MAP OF NORTHERN MICHIGAN

Showing location of principal areas of soft-ore production, by townships, and locations of areas now under active consideration or development as sources of low-grade concentrating ore ("taconite"). Isograds shown: B—biotite; G—garnet; St—staurolite; Si—sillimanite. Boundaries of Keweenawan and Paleozoic strata shown by dashed lines.

LAKE SUPERIOR
KEWEENAW
KEWEENAW BAY
HOUGHTON
MARQUETTE
BARAGA
DICKINSON
IRON
ONTONAGON
GOGEBIC
IRON
MICHIGAN
WISCONSIN
EXPLANATION
More than 100,000,000 tons
25-100,000,000 tons
5-25,000,000 tons
Less than 5,000,000 tons
Production, by townships, of soft ores
Through 1950
Location of area under active consideration or development as source of concentrating ore ("taconite")
B - biotite
G - garnet
Isograd
S - staurolite
Si - sillimanite
0 10 20 Miles
SCALE

FIGURE 3.

preciated by comparison of the photomicrographs shown in Plate 5 but is even more apparent in Figures 5 and 6 of Plate 4, where polished sections of hematitic iron formation of

TABLE 8.—ORE PRODUCTION, CLASSIFIED ACCORDING TO METAMORPHIC ZONES

Production, in millions of tons, by townships	Number of areas				
	Chlorite zone	Biotite zone	Garnet zone	Staurolite zone	Sillimanite zone
More than 100	1	0	0	0	0
25–100	7	2	0	0	0
5–25	6	1	0	0	0
Less than 5	5	4	0	2	0

Note: the tabular classification does not agree exactly with the distributions shown on Figure 5, because production is shown on the map as a circle at the center of the township concerned, whereas actually the production may have been from within a lower zone in a township that is crossed by an isograd. The discrepancy is notable only in the "Less than 5" group, in which production from the Felch district and from the west Marquette district is shown in the garnet zone on the map whereas actually the ore was produced from areas within the staurolite zone.

originally similar character are compared. The specularite blades in the specimen from the lower zone of metamorphism are typically about 0.01 mm in length—much too fine to be separated by economically feasible grinding—whereas in the specimen from the staurolite zone they are much larger and can be separated by grinding to screen sizes of 200 mesh.

The role of grain size is totally different in development of the soft-ore deposits. These ores commonly are thought of as the result of oxidation of iron-formation, which they are in part. But a more important geological factor is the removal of silica by actual leaching or by replacement. Oxidized iron formation is found in all metamorphic zones, but only in the lower zones has the silica been removed in quantity. The reason for this limitation appears to lie in the relative grain size of the quartz, which ranges from about 0.01 mm in the areas of least metamorphism to as much as 0.5 mm in areas of highest metamorphism. Replacement along grain boundaries, which is evident in thin sections of partly altered iron formation as the method by which the silica is attacked, needs to penetrate only to a depth of about 0.005 mm to effect the complete removal of silica in a rock such as shown in Figure 1 of Plate 5, whereas such depth of penetration would leave a rock from the higher zones virtually unaffected. The instability of particles with large surface: volume ratios, and the much greater irregularity of grain outlines in the fine-grained rocks are also important factors.

RELATIONSHIP BETWEEN REGIONAL METAMORPHISM AND INTRUSIVE IGNEOUS ROCKS

The relationship between regional metamorphic zones and igneous rocks of the same general orogenic cycle rarely is obvious. In the Scottish Highlands, for example, the isograds are rudely concentric with respect to a zone of regional injection, yet, according to the map given by Kennedy (1949, p. 54), the boundaries of regional injection cross the isograds to some extent, and many large masses of granite lie well outside this central zone. In general, however, the quantitative expression of igneous activity is greatest in the areas of highest metamorphic grade, a fact that has led some workers to the conclusion that the granitic bodies themselves are the end products of metamorphism—that is, that they are ultrametamorphic rather than igneous in origin. (*See*, for example, Read, 1939.)

The core regions of the metamorphic nodes in Michigan are much smaller in surface area than the zone of regional injection in the Scottish Highlands. The Peavy node of southeastern Iron County and adjacent Dickinson County is the only one of the principal metamorphic centers that is sufficiently well mapped to assess the distribution of post-Huronian granite and its relation to the metamorphic zones. A belt of scattered small intrusive bodies —mainly dikes and stocks—extends from the vicinity of Crystal Falls on the west, through the nodal area, into the Felch district of central Dickinson County. These bodies range in size from dikelets that are only inches wide to tabular or elliptical masses as much as a mile

across. The general trend of the belt is easterly, parallel or nearly parallel to the axis of the metamorphic high.

The intrusive bodies of the Peavy node are not restricted to the core region; at the west end, near Crystal Falls, several small granite stocks cut Huronian slate that is within the chlorite zone. Most or all of the bodies have sharp-walled contacts and are of uniform composition though they cut rock as dissimilar as iron formation and dolomite. The level of metamorphism of the adjacent rocks has little or no relation to individual intrusive bodies; in fact, the common alteration of metamorphic silicates to chlorite and serpentine immediately adjacent to granite dikes suggests that the granite may have exerted a retrograde influence. In the core area itself, intrusive rocks are more abundant and complex than those in lower zones of metamorphism. The rocks range in composition from ultrabasic to granitic (Clements and Smyth, 1899). Recent U. S. Geological Survey studies by R. W. Bayley (unpublished report) have shown that the bulk of the exposed igneous rock is gabbroic to dioritic and that these rocks, together with the adjacent hornfelses and mixed rocks, have been regionally metamorphosed and are therefore premetamorphic. Granitic intrusive rocks are less abundant than intermediate or basic rocks in the core area, though more abundant than elsewhere along the Peavy belt of intrusives, and in general they are post-metamorphic.

The core region of the Republic node of southeastern Marquette County is very poorly exposed, but it appears to center approximately at the contact between Huronian strata and granitic crystalline rocks. Largely because the Huronian strata in the vicinity of Republic and the western part of the Marquette range are highly metamorphosed and cut locally by granite dikes, Lamey (1931, 1933) concluded that the large mass of porphyritic granite that is exposed between Republic and the Marquette district is of post-Huronian age. Inasmuch as this granite is areally continuous with granite to the east and south, Lamey (1934, 1935, 1937) later classified the entire "southern complex" of southern Marquette and Dickinson counties, previously considered pre-Huronian, as post-Huronian. However, detailed mapping in Dickinson County by Pettijohn (1943), and by the U. S. Geological Survey (in which Lamey has participated) has shown that at least the framework of the crystalline blocks is pre-Huronian. The Republic area has not yet been mapped in detail, but outcrops along Highway M-95 northeast of Republic indicate pre-Huronian age for the major part of the granitic rocks. Many of these exposures show basic dikes cutting the granite and migmatite. The dikes, which sharply truncate gneissic and migmatitic structures in the granitic host, appear unmetamorphosed, but actually the rock is amphibolite, with a mineralogy—hornblende and andesine, chiefly—entirely of secondary origin. The gneissic and migmatitic host rock must therefore have originated during an earlier interval of metamorphism and intrusion, and it must be of pre-Huronian age.

The core region of the Watersmeet node is even more poorly exposed than that of the Republic node. Allen and Barrett (1915) designated part of the granitic rocks exposed at the eastern end of the Gogebic range as the Presque Isle granite, and assigned this a post-middle Huronian age on the basis of an increase in metamorphic grade of the Palms quartzite and of the Ironwood iron formation in that area. The most specific evidence is the cross-strike transition of the Palms quartzite into schist and gneiss in secs. 21 and 28, T. 47 N., R. 43 W. The northern outcrops contain much chlorite and sericite, and the rocks "do not differ in mineral composition and texture from similar exposure of the Palms formation in other parts of the range" (Allen and Barrett 1912, p. 42). The rock in the southern part of the exposures is "hornblende gneiss or mica schist cut by numerous veins of pegmatitic and granitic material." This rock was believed to be Palms formation metamorphosed by intrusive granite. However, inspection of the map in the Allen-Barrett report shows that the strata of normal Palms aspect have a cross-strike width adequate to include the normal thickness of the formation at the recorded dips. Mr. Barrett (personal communication) now considers the metamorphic rocks previously assigned to the Palms to be part of the pre-Huronian basement. Furthermore, the

rocks east, west, and south of this area are definitely in the chlorite zone of metamorphism, so that the assumption of younger granite and related metamorphism in this area is questionable. Two other masses of "younger granite" are shown on Figure 1 of the Allen and Barrett report and on more recent maps (Leith, Lund, and Leith, 1935; Martin, 1936) between Watersmeet and Lake Gogebic. Other than the generally high metamorphic grade of the Paint slate and Wolf Creek schists, which are correlative with the Michigamme slate, no evidence fixes the age of the granitic rocks, which physically resemble the pre-Huronian granitic gneisses more than they do the post-Huronian granites of other parts of the region. Other areas—northeastern Iron County, for example—show similar distribution patterns of granite and metamorphic rocks that are without genetic relationship. In the absence of definite evidence to the contrary, therefore, these granitic masses in the Watersmeet area are here considered to be pre-Huronian.

Several generalizations bearing on the problem of granite-metamorphism relationships in northern Michigan are summed up as follows:

(1) The post-Huronian intrusive granitic rocks consist mainly of dikes and small stocks, few of which are as much as a mile in diameter. These bodies are most abundant in the higher metamorphic zones but are not confined to them.

(2) The metamorphic zones are not symmetrically distributed with respect to any single body of post-Huronian intrusive granite or to any clearly defined group of such granite bodies.

(3) The great majority of the granite bodies of accepted post-Huronian age can be shown to be post-metamorphic—that is, they were intruded into rocks that already had attained their present metamorphic rank.

(4) The post-Huronian granitic rocks appear to be truly igneous rather than ultrametamorphic in origin. This is indicated by their uniform composition even though they cut highly diverse rock types, their sharp contacts, and the presence of such typical pyrogenic features as normally zoned plagioclase.

Relationship between Metamorphism and Structure

METAMORPHIC ZONES AND REGIONAL STRUCTURE: The distribution of the metamorphic zones (Pl. 1) shows a lack of correlation with regional structure. This lack of correlation applies not only to the structural trends within the Huronian strata but also to the outlines and trends of the pre-Huronian crystalline blocks. In northeastern Iron County, for example, the metamorphic gradient rises continuously to the northeast, across the "ovals" of pre-Huronian granite gneiss, and the positions of the isograds show no reflection of these crystalline blocks.

A number of major faults are now known in the region, although few appear on published maps. In at least one area—the southeastern part of T. 41 N., R. 30 W. in central Dickinson County—mapping by James Trow (Personal communication) has shown that dikes that are entirely metamorphosed cut across or follow some of these faults, which demonstrates the post-structural age of the metamorphism.

INTENSITY OF METAMORPHISM IN RELATION TO INTENSITY OF DEFORMATION: Little or no correlation exists between the relative intensities of metamorphism and deformation. Some areas of high metamorphic grade are strongly deformed; others are not. The Huronian rocks of the Marquette district occur in a syncline that extends across several zone boundaries, but the strata do not show a parallel increase in deformation. The Michigamme slate in the sillimanite zone of the Peavy node in southeastern Iron County is tightly folded—but no more so than the rocks of the Iron River-Crystal Falls district, which is entirely within the lowest zone of metamorphism. Internal deformation of the rocks may be greater in the more highly metamorphosed areas, yet even here the correlation is not close. Originally calcareous concretions in the sillimanite schists of the Peavy node have been drawn out to axial ratios of 10–20:2:1, yet in the heart of the Republic node the iron formation contains undeformed oöliths. In general, the field data in northern Michigan refutes the view that heat developed during deformation is a major factor in producing metamorphism in the

affected rocks; in fact, at least for this area, deformation and metamorphism are almost entirely independent variables, related only in that both are expressions of some deep-seated energy release in the crust.

TIME RELATIONSHIPS BETWEEN METAMORPHISM AND DEFORMATION: If metamorphism and deformation are separate variables in the post-Huronian orogenic scheme, then the two need not be strictly contemporaneous. Field evidence lends some support to this inference.

The Felch district of central Dickinson County is essentially a synclinal downwarp of Huronian strata between two blocks of older granite. The syncline contains, in ascending succession, the Sturgeon quartzite, the Randville dolomite, the Felch schist, and the Vulcan iron formation, with dikes and sills of pre-metamorphic basic igneous rock. The area is within the staurolite zone of metamorphism. The quartzite, dolomite, iron formation, and basic igneous rocks show little or no preferred mineral orientation. The iron formation contains grunerite—a bladed mineral that might be expected to reflect deforming forces—as rosettes and scattered blades entirely without preferred orientation. Tremolite and diopside show similar features in the dolomite, and universal-stage examination of dolomite from the Metronite quarry by Peter R. Vail, at Northwestern University, shows that the carbonate also has random orientation. At least the peak of the temperature rise must have been attained after deformation had ceased. However, the Felch schist, stratigraphically between the iron-formation and the dolomite, does have a strong fabric dominated by parallel or subparallel flakes of biotite and muscovite. In view of the evidence from adjacent rocks, this fabric might be interpreted as a result of mimetic growth parallel to original bedding planes or to the localization of shearing in this particular unit. But it may also mean that the micas were formed in these shaly rocks during deformation, but at a time before the temperature reached the peak that was to result in development of higher grade silicates in the iron formation and dolomite. The Felch district is of further interest because the granite dikes common to the area were intruded after metamorphism. The events in the post-Huronian orogenic interval, *for this area*, thus can be established in the time sequence of: (1) deformation, (2) metamorphism, and (3) granite intrusion.

Andalusite-staurolite relationships in other parts of the region, notably in the staurolite zone northwest and southwest of Republic, may also be significant in the relative timing of temperature and deformation. The typical habit of andalusite in this association is as pods or augen (Pl. 2, fig. 2), and in some places the andalusite forms knots in a swirled mica schist. The staurolite, on the other hand, is idiomorphic. Andalusite is commonly referred to as an antistress mineral, and staurolite as a stress mineral, and though it is difficult to see the theoretical basis for the classification of minerals as stress or antistress, yet andalusite is a common constituent of high-temperature assemblages formed under conditions lacking in shearing stress and is rare elsewhere, whereas the opposite is true of staurolite. The observed features of the andalusite-staurolite rocks are interpreted to indicate that in these parts of the region the temperature reached a high level, possibly its peak, before deformation intensity reached significant levels; that the andalusite formed large individuals, probably originally idiomorphic, under conditions of almost straight thermal metamorphism; and that with passage of time the stress factor increased and the temperature level remained high, with the result that the andalusite crystals were rounded and partly destroyed by shearing while staurolite developed as well-formed crystals in accordance with temperature conditions prevailing and in accordance with its characteristics as a stress mineral.

These two examples, if interpreted correctly, indicate that in one area the temperature peak was reached after deformation and in the other that the temperature peak—or at least a high level—was reached before the peak of deformation. They support the proposition that stress and temperature were not directly related forces.

CAUSE AND TEMPERATURE OF METAMORPHISM

The metamorphic zonation is due to thermal gradients that were in existence during or im-

mediately following the post-Huronian—pre-Keweenawan orogenic interval. The concept of different metamorphic facies produced at one temperature level because of variations in water content of the rocks (Yoder, 1952) is not applicable, inasmuch as the isograds cross lithologic units that had nearly uniform composition before metamorphism.

The source of heat required for metamorphism is not clearly evident. If metamorphism was caused by heat exuded from crystallizing magma, then the main body of magma must have been somewhat below the present level of erosional truncation, as the field relations show that the *exposed* post-Huronian granitic rocks were, in general, emplaced after the enclosing rocks had been metamorphosed. An alternate viewpoint to that of a large body of subjacent magma is that both the metamorphism and the granite are thermal results of unexplained nodal rises of temperature in the crust—the one produced by solid-state mineral changes and the other by local partial melting and subsequent emplacement as dikes.

Consideration of the probable thermal gradients involved should be of some aid in choosing between these two principal alternatives. The maximum temperature attained during the period of thermal disturbance is not directly determinable because of lack of knowledge of phase transformations, but Rosenqvist (1952) has calculated from thermodynamic data the P-T positions of the principal metamorphic facies. A diagram slightly modified from his is given as Figure 4. On it are plotted, as dashed lines, the approximate positions of the isograds, as derived from field relationships in northern Michigan between the index minerals of the zones and the mineral assemblages described by Rosenqvist as characteristic of his facies. Rosenqvist's conclusions as to the minor role of pressure down to depths of 10 km or more, reflected in the steepness of the isofacial lines, may not be valid, but if this diagram is even approximately correct the general level for the sillimanite zone at depths of 5 km would range upward from about 600° C. According to Goranson (1932), a rock of granitic composition, with 6.5 per cent water at 1000 bars pressure, may become partly molten at about 700°C. The absence of rock of migmatitic aspect in the core regions of the metamorphic nodes, except locally around premetamorphic bodies of intermediate or basic composition, suggests that the temperature peak during metamorphism did not reach this value, at least at the present level of truncation. Inference and available data thus indicate that the temperatures at the exposed nodes reached a maximum of 600°–700°C.

The temperature represented by the chlorite zone, according to the Rosenqvist diagrams, would be 200°C or less, which indicates that the temperature differential that is now represented by the metamorphic zonation was about 400°C. The dip of the isograds separating the zones is not known, but it may be assumed that the dip is steepest where the isograds are most closely spaced. On both the north and south flanks of the Peavy node the distance from the sillimanite isograd to the chlorite zone is no more than 4 miles; with the estimated temperature differential of 400°C; this means that the horizontal thermal gradient was 100° or more per mile, or roughly 1° per 50 feet. Assuming a conductivity of 5×10^{-3} cal/sec. cm deg. the heat flux necessary would be about 3×10^{-6} cal/cm^2 sec.

Radioactive decay is the only obvious source of nonmagmatic heat (other than frictional heat, which is not considered here because of the demonstrated lack of relation between deformation and metamorphism). The amount of heat generated in the average granite by radioactive decay of uranium, radium, thorium, and potassium is about 5.1×10^{-13} cal/cm^3 sec. (Jeffreys, 1952, p. 283). If a rock mass existed at the center of a metamorphic node with ten times the radioactivity of the average granite, or a heat generation of about 5×10^{-12} cal/cm^3 sec., and if this body were a vertical cylinder that extended to the level of the present surface, then the development of a flux of 3×10^{-6} cal/cm^2 sec.—the amount necessary to produce the required thermal gradient—would require a cylinder of 20 km diameter. In places the total width of a node, including both flanks down to the chlorite zone, may be as little as 13 km, and high radioactivity is absent in the core area; these facts rule out such a possibility and any other geologically reasonable combination of dimensions and radioactivity.

Evidently the heat for metamorphism was

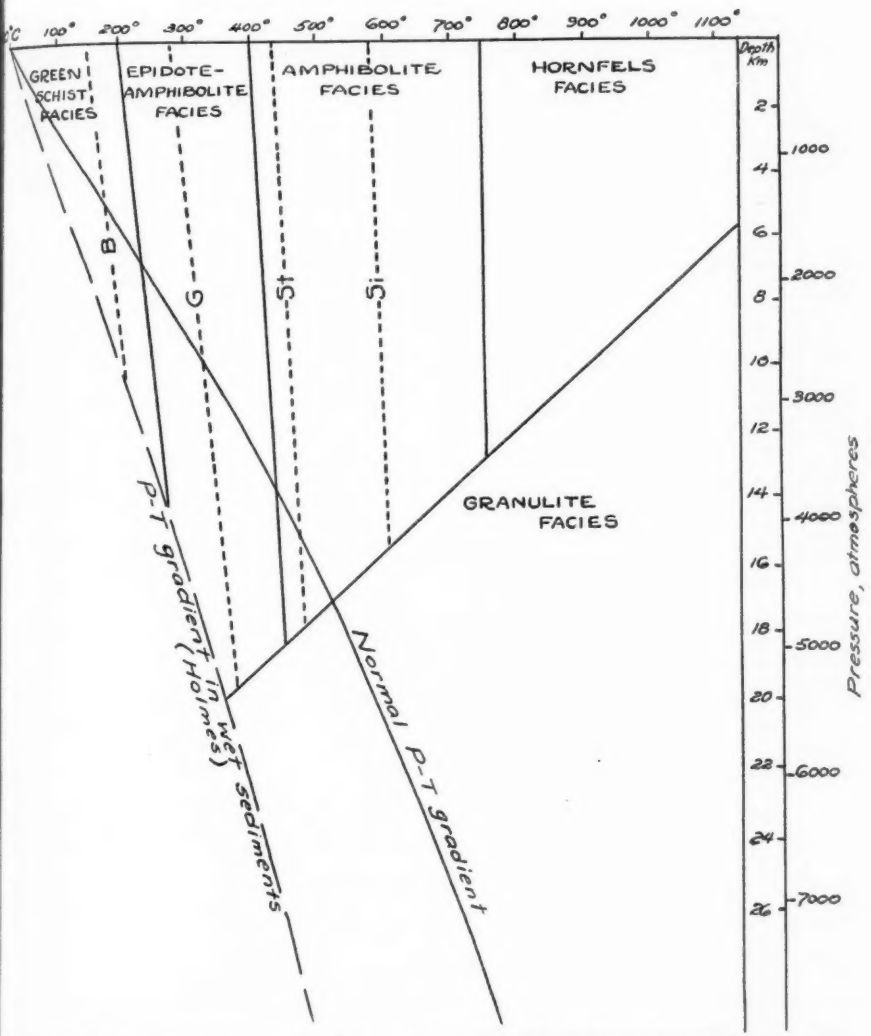

FIGURE 4.—TEMPERATURE-PRESSURE CONDITIONS FOR THE MAIN FACIES IN THE EARTH'S CRUST (From Rosenqvist, 1952, p. 101) Some material deleted from Rosenqvist's original diagram, and isograds added (B—biotite; G—garnet; St—staurolite; Si—sillimanite) in positions in accord with relationships observed for metamorphic rocks in northern Michigan.

derived from subjacent bodies of magma, by means of which heat acquired at greater depth was transferred by mass movement to higher levels in the crust. The central part of a metamorphic node presumably lies above the highest part of a subjacent body. On the basis of an estimated temperature of 600°C or more for the sillimanite zone and a thermal gradient that would have been a minimum of 1°C/50 feet, the magma was not more than a mile, and possibly was considerably less, below the present surface at the core region of a node.

RETROGRADE METAMORPHISM

Turner (1948, p. 299) defines retrogressive (or retrograde) metamorphism as follows: "Retrogressive metamorphism or diaphthoresis

is the mineralogical adjustment of relatively high-grade metamorphic rocks to temperatures lower than those of their initial metamorphism", and on page 300 he states: "The criteria of retrogressive metamorphism are almost entirely mineralogical."

Retrograde alteration is a widespread feature of the metamorphic rocks in northern Michigan. The major mineralogic changes are alteration of dark minerals (pyroxene, amphiboles, garnet, and biotite) to chlorite, and of lighter minerals (plagioclase, orthoclase, staurolite) to sericite. Alteration to minerals of intermediate grade is much less common than that to minerals of low grade, but it is evident in some rocks; the hornblende in amphibolite, for example, is often bound altered from the green variety of the higher zones to a blue-green variety common to the intermediate zones.

The distribution of retrograde effects has not been studied quantitatively, but the alteration obviously is extensive and has profoundly modified both the mineralogy and the chemical composition of the rocks. Alteration of as much as a fourth of the metamorphic minerals of higher grade to chlorite and sericite is common, and in some the alteration is virtually complete. Most of the rocks showing retrograde effects are unsheared, and alteration is pervasive. Internal deformation is not necessary for alteration, although the presence of retrograde products along fracture or shear planes in otherwise unaltered rocks shows that formation of the lower-grade minerals certainly is favored by such internal movements.

In general, the retrograde metamorphism involves development of minerals more hydrous than those preceding, a fact pointed out by Schwartz and Todd (1941). In a mass of graywacke and schist such as that in the Calumet trough of central Dickinson County, in which the rocks contain about 25 per cent biotite and the biotite is approximately 25 per cent altered to chlorite, the apparent net increase in water is about 4×10^7 tons per cubic mile of rock. The significance of this is not clear. Water could have been introduced from an outside source, as implied by Schwartz and Todd, but other interpretations are possible. It could be original water in the rock which for reasons of low permeability and lack of open fractures did not escape during the temperature rise. The higher-grade minerals would have formed in equilibrium with a dense vapor trapped in the pore spaces, a vapor which at lower temperatures would react with the earlier-formed minerals to give the present retrograde assemblage. The pervasiveness of the alteration tends to support such a concept.

Recent experimental work by Yoder (1952) has shown the profound effect of water on assemblages formed at a fixed temperature. He writes (p. 615): "At approximately 600° and 15,000 psi, it is possible, therefore, to have assemblages suggestive of every one of the now accepted metamorphic facies in stable equilibrium." If it were not for the clear-cut evidence showing that higher-grade minerals did previously exist in the rock, the conclusion might be justified that the apparently retrograde rocks actually were formed at the same time and at the same temperature as those of higher grade in adjacent positions, simply in consequence of original differences in water content.

The major question that must be answered before the significance of the retrograde metamorphism is understood is whether or not the system was open or closed. If the latter, which seems most probable, then the retrograde effects are an integral part of the regional metamorphism. Variations from place to place in the intensity of retrograde alteration would be related principally to local differences in permeability and structure which controlled the amount of water driven off during the temperature rise.

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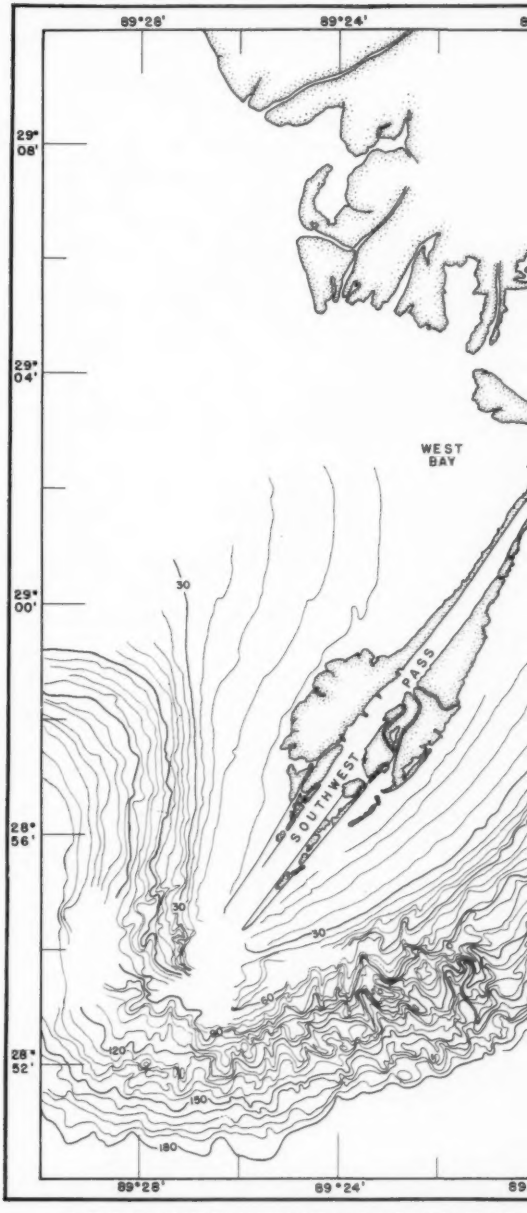
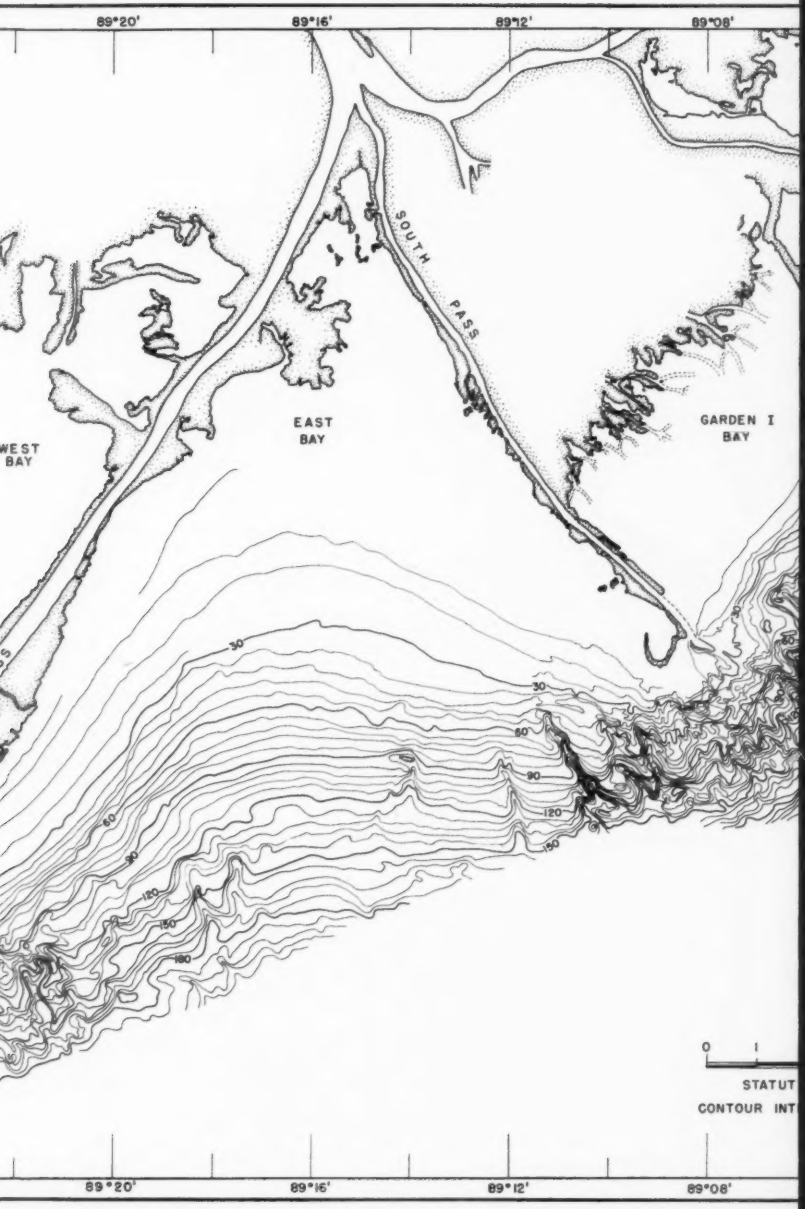


SUBMARINE TOPOGRAPHY



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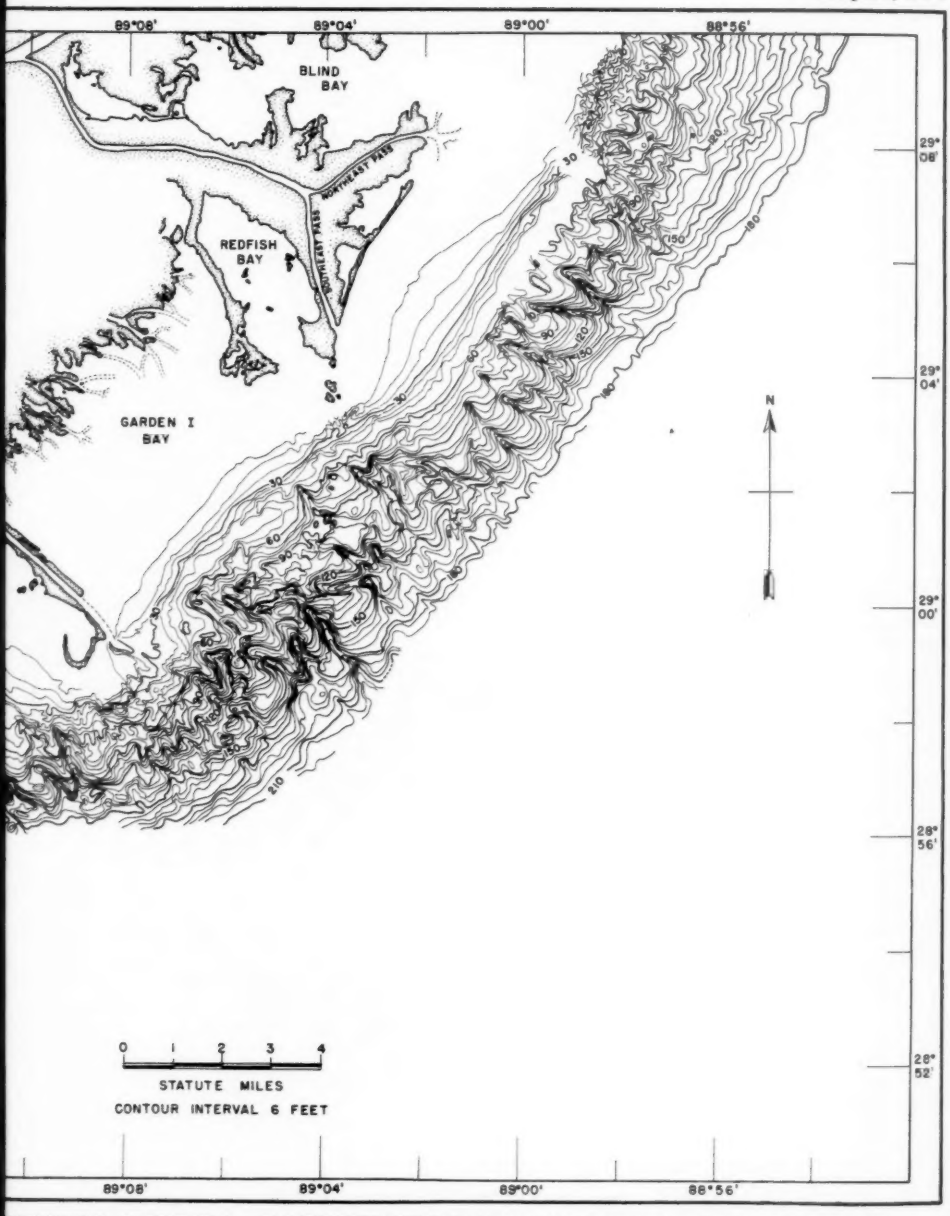

SSIPPI DELTA, SOUTHWEST TO NORTHWEST PASSES

f the U.S. Coast and Geodetic Survey

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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DELTA-FRONT VALLEYS BORDERING THE MISSISSIPPI DISTRIBUTARIES

By FRANCIS P. SHEPARD

ABSTRACT

Shallow discontinuous valleys crease the upper portion of the continental slopes in the region where the Mississippi Delta has built across the shelf. These valleys attest to the instability of the forward-growing slope despite its average inclination of only 1 per cent. Mass movements probably of the earthflow type appear to be the cause of the valleys rather than turbidity currents because deposits from valley floors show no concentration of sand by currents, and many of the valleys are not located at points where large discharge of sediment-laden water could produce turbidity currents. Furthermore, depressions and hills along the courses of the valleys and their short length differentiate them from the long continuous slightly incised valleys which are outer continuations of submarine canyons and which are generally ascribed to turbidity currents. The delta-front valleys shift position as the slopes are built forward.

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INTRODUCTION

During the study of marine sedimentation bordering the Mississippi Delta, which constitutes one of the objectives of a grant from the American Petroleum Institute (Proj. 51), the writer had an opportunity to investigate the shallow submarine valleys found in the slopes bordering the most advanced portions of the Mississippi Delta. These valleys are clearly shown in the unpublished hydrographic sheets of the U. S. Coast and Geodetic Survey. Interest in such valleys stems partly from discussions of the origin of submarine canyons. Shallow valleys cutting the submerged delta fronts in the lakes of Switzerland have been attributed by Daly (1936, p. 413–418) to erosion by turbidity currents. The shallow valleys found as the outer extensions of submarine canyons have been compared to those of the Swiss

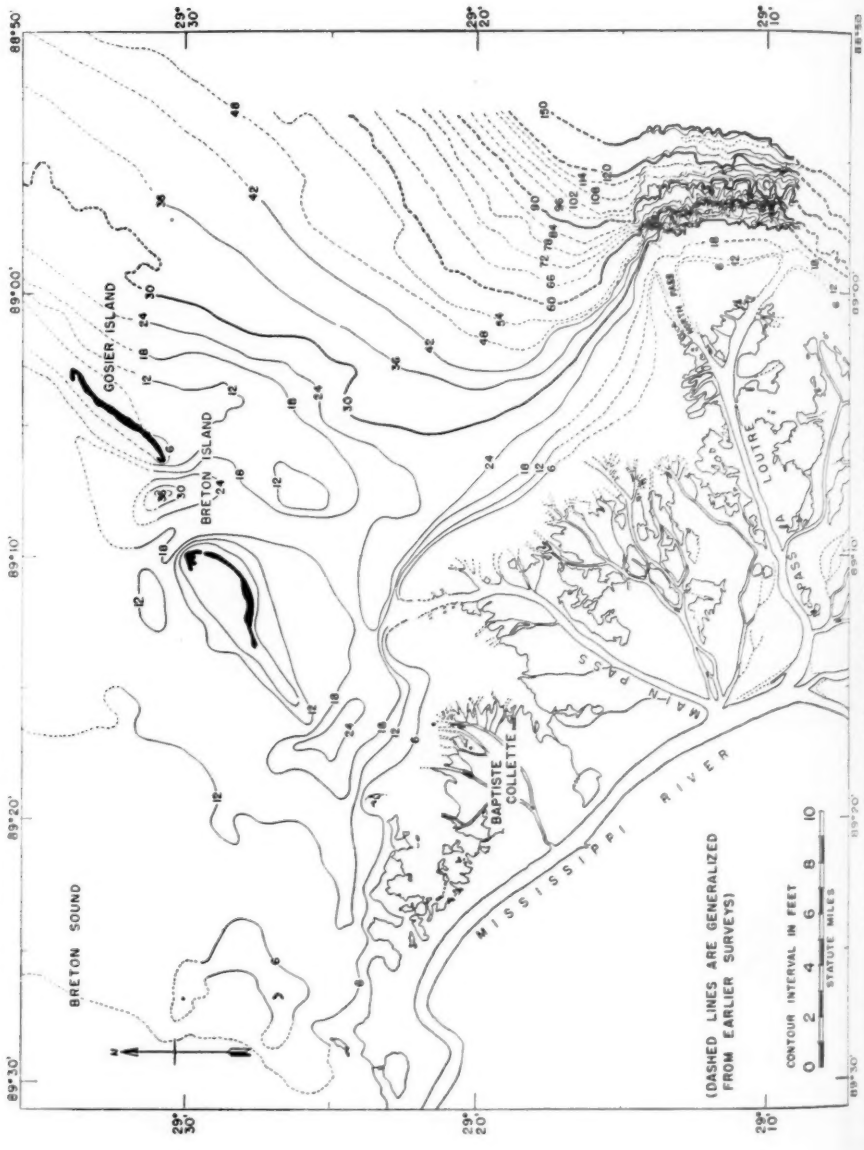


FIGURE 1. SUBMARINE TOPOGRAPHY OFF NORTHEAST PORTION OF BIRDFOOT DELTA

deltas (Shepard, 1952, p. 88) and similar valleys called deep-sea channels have been found on the deep floor of the Atlantic (Ewing *et al.*, 1953), the Pacific (Menard, 1955; Dill *et al.*, 1954), and of the Indian Ocean (Dietz, 1953). All these deep valleys have also been attributed to turbidity currents.

The shallow valleys bordering the Mississippi Delta offered the best available opportunity of obtaining sounding details which would allow the construction of comparatively accurate contours. Furthermore, the Scripps surveys compared to earlier soundings served to show the changes in the valleys accompanying the forward building of the delta front. It was appreciated, however, that evidence concerning the origin of the Mississippi Delta valleys would not necessarily apply either to the valleys of the Swiss Lakes nor to the deep-sea channels of the ocean basins.

Acknowledgments

Appreciation is expressed to P. C. Scruton, J. R. Curray, G. A. Rusnak, and D. G. Moore for collecting some of the samples and for making some of the surveys on which the present paper is based, also to D. M. Poole and H. W. Lusk for their analyses of the sediment samples, and to J. R. Moriarty for the drafting. This investigation was supported by a grant from the American Petroleum Institute, Project 51.

Distribution and General Character of the Valleys

Charts of the Mississippi Delta area (Fig. 1; Pl. 1) indicate that the valleys extend from North Pass to Southwest Pass, but are poorly developed between South and Southwest Pass. No valleys are found around the rest of the delta. They are concentrated in the zone where the Mississippi Delta has built across the continental shelf, so that several distributaries are actually pouring their sediment-laden waters onto the continental slope. Despite the rapid growth of such distributaries as Main Pass and Baptiste Collette (Fig. 2), the valleys are missing off the distributaries on the northeast and southwest sides of the delta. Off these passes the river delta is growing out onto a relatively flat continental shelf. Off East Bay, between South and Southwest passes (Pl. 1), valley development is poor in the gap between major passes where the shelf is relatively broad, shallow, and indented. The valleys are developed best near South Pass and for about 3 miles east and west of that pass. The very prominent valley west of South Pass (Pl. 1) appears completely unrelated to any active pass, but the nineteenth century charts show that there was a prominent distributary, Grand Pass, near the head of this valley (Fig. 2). Like South Pass, Grand Pass had been built out to the edge of the shelf, and at one time these two distributaries constituted the most forward-built structures of the Mississippi Delta. Southwest Pass has been building diagonally out onto a broad ridge (Fig. 3).

Detailed soundings recorded on the unpublished hydrographic sheets of the U. S. Coast and Geodetic Survey show that these valleys are short and discontinuous, starting near the top of the slope and extending down to depths which rarely exceed 200 feet (Pl. 2)[1]. The valley floors lie from a few feet to about 50 feet below the adjacent ridges. The valleys have very few tributaries; most of them terminate in fanlike features, some have basin depressions along their courses, and a few have small hills.

Most of the valleys are about one-third to two-thirds of a mile wide. They commonly are 2–4 miles long. In some places valleys die out, and adjacent to the terminations others start in along the slope. Soundings outside this area are not so complete as those on which the valleys are based, but lines along the slope are sufficient to indicate that beyond the 200-foot contour valleys are inconsequential if they do exist.

The valleys have gradients of about 1 per cent near South Pass and have slightly gentler gradients off Southwest Pass and off Pass a Loutre. This gradient is approximately the same as the slope of the delta front in this area, and the same slope continues down to

[1] The soundings on which the contours are based are included, so that readers may make their own contour interpretations.

the deep parts of the Gulf of Mexico with little interruption. The walls of the valleys are steeper than the general gradient. In echo-sounding profiles taken by the Scripps A.P.I.

each about 6 feet deeper and the third has the same depth.

In seven localities cores 1–4 feet long were collected on the floor of the valleys and on

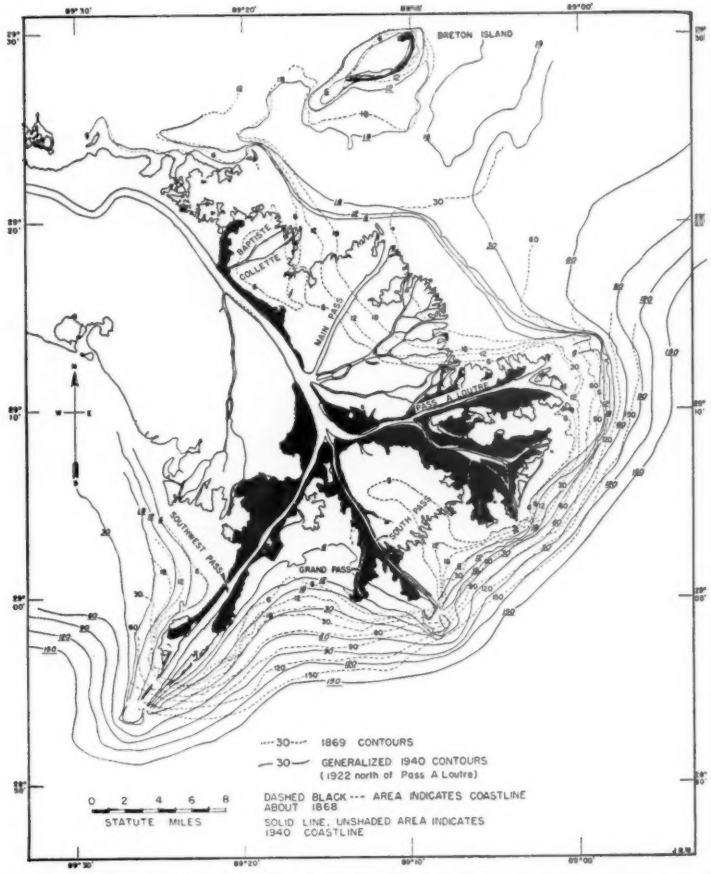


FIGURE 2.—COMPARISON OF OLD AND NEW OUTER DELTA OF THE MISSISSIPPI RIVER, WITH GENERALIZED CONTOURS SHOWING THE DEPTH CHANGES SINCE APPROXIMATELY 1869

project, slopes up to about 15° are indicated (Fig. 4). These same soundings show that the valley profiles include V shapes, flat floors with steep sides, and U shapes with an inner gorge. One valley has a small hill rising from the flat floor. Comparisons of the two sounding lines in Figure 4, which were made off the same area and separated by about 1500 feet, show that in the outer line two valleys are

adjacent ridges. Three were obtained during high-water stages of the Mississippi River two directly after high water. In five of these pairs very similar material was found on ridge and valley, and the cores indicate no difference in the nature of sedimentation in the two environments. In the other two pairs the sediment was slightly more compact underneath the valley than on the adjacent ridge. The

ediments of all 14 cores are silty clays or layey silts characteristic of the delta front nd all but one have thin interbedded sand aminae. The sand-silt-clay content of the top 0 cm of these cores is given in Table 1.

A comparison between the 1940 survey and one made by Scripps Institution in 1953 and 1954 shows a distinct change here during the last 13 or 14 years (Fig. 6). Here, also, the whole slope has moved forward, and some

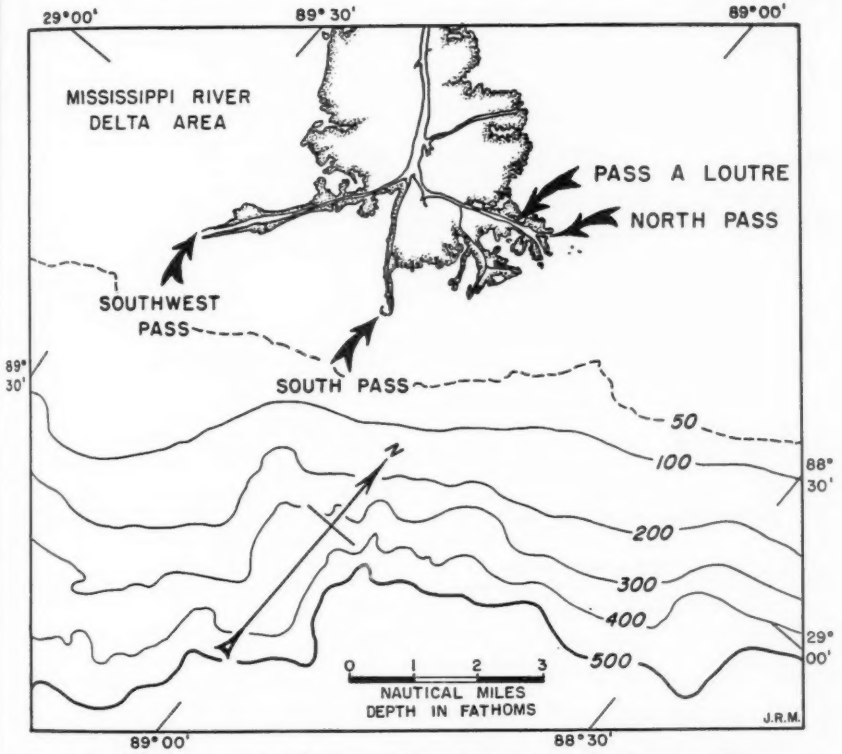


FIGURE 3.—CONTOURS OFF THE MISSISSIPPI DELTA SHOWING HOW THE ADVANCED PORTIONS HAVE CROSSED THE CONTINENTAL SHELF

RELATION TO FORWARD-GROWING FORE-SET SLOPES

Comparison of profiles made off Pass a Loutre, South Pass, and Southwest Pass between 1860 and 1871 with profiles of the 1940 survey, covering approximately the same lines, shows that the slopes off these passes have been moving forward en masse about one-half to 2 miles (Fig. 5). The inclination of the slopes has remained about the same. This is also indicated in Figure 2 where the contours of the old survey are superimposed on generalized contours of the 1940 survey.[2]

[2] Valleys are omitted from the recent surveys to make meaningful this comparison because of the absence of sufficient soundings to show the valley pattern on the old surveys.

valleys have changed position. At "A" in Figure 6 the 90-foot contour shows a ridge where there was a valley and just to the north a valley where there was a ridge. The same shift continues for a mile to the south. Elsewhere, however, the valleys have not changed position. At "B" some new valleys have formed and an old valley has been filled.

ORIGIN OF DELTA-FRONT VALLEYS

Two hypotheses can be offered to explain the small valleys off the Mississippi Delta.

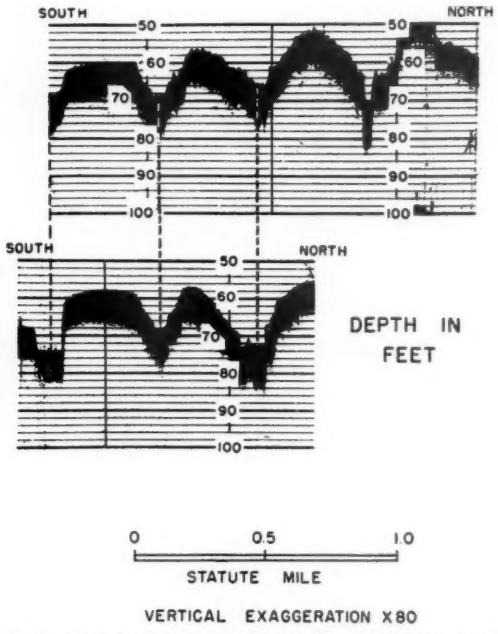


FIGURE 4.—FATHOGRAM PROFILES OF THE DELTA-FRONT VALLEYS OF PASS A LOUTRE
The two profiles are 1500 feet apart and show the changes in three valleys in that distance.

TABLE 1.—COMPARISON OF VALLEY AND RIDGE SEDIMENTS

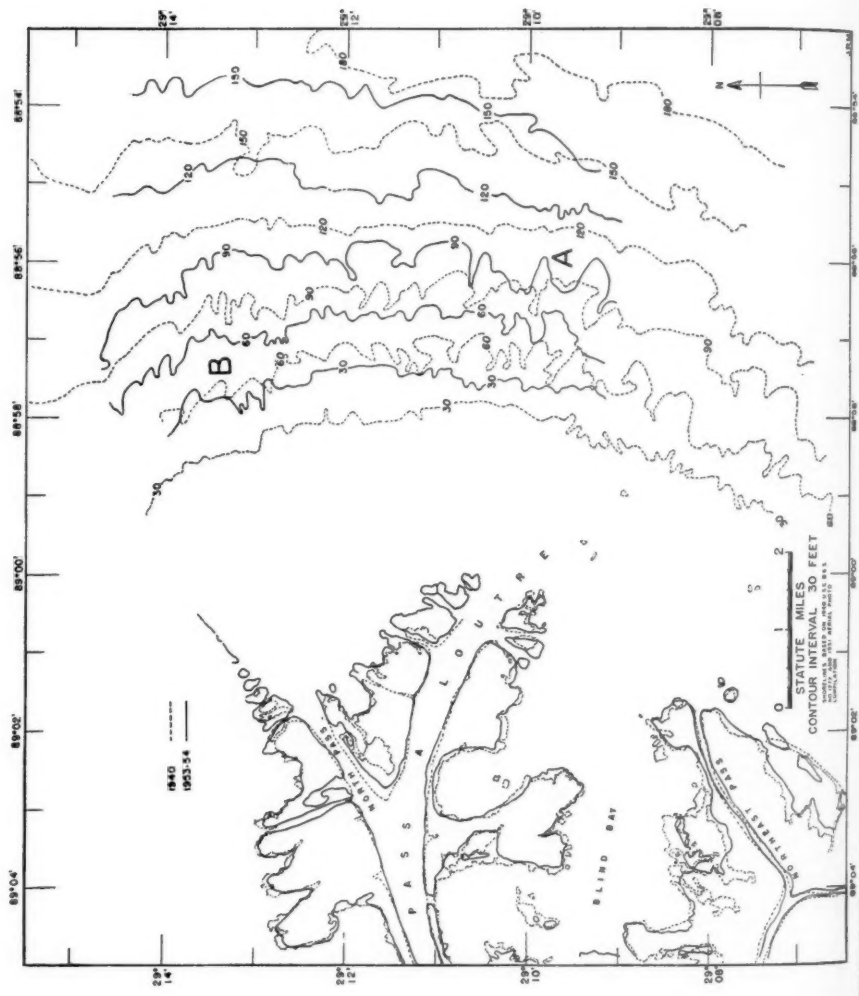
Valley core					Ridge core					General location
Core nos.	Depth (feet)	Sand	Silt	Clay	Core nos.	Depth (feet)	Sand	Silt	Clay	
275A	37	0	40	60	275B	28	0	37	63	Off Pass a Loutre
519A	69	2	44	54	519B	60	1	42	57	Off Pass a Loutre
520A	60	0.1	55.9	44	520B	48	0.3	53.7	46	Off North Pass
704	54	1.7	52.7	45.6	705	42	0.8	53	46.2	Off South Pass
712	66	0.4	56	43.6	711	42	0.3	43	56.7	Off South Pass
746	68	0.1	39.1	60.8	747	58	0.2	47.2	52.6	Off Pass a Loutre
749	75	0.1	38.9	61.0	748	51	0.2	48.9	50.9	Off Pass a Loutre

One is that they were cut by turbidity currents generated by the large quantities of sediment coming from the active passes. As this sediment settles to the bottom of the water mass, density currents could cascade down the slope towards the deep floor of the Gulf of Mexico. These currents may be expected to flow every year during the high-water stages[3] of the Mississippi. If such currents are strong enough to be the cause of the valleys, however, they should concentrate the coarser sediments along the valley axes forming a sandy bottom, particularly since all the delta-front cores show that sands are available. Therefore, the finding of cores taken during high water with no sand concentrates at or near the surface renders doubtful a turbidity-current origin.

Other continental slopes show evidence that turbidity currents are capable of continuing

[3] Owing to flood-control measures high water is almost the same in height, although not in duration, each year.

FIGURE 5.—PROFILES SHOWING THE FORWARD GROWTH OF THE SLOPE OFF THE MAIN PASSES OF THE MISSISSIPPI DELTA
Note that the slope has remained essentially constant off all passes.


A
B
1940
1953-54
PASS A LOUTRE
BLIND BAY
SOUTHEAST
NORTHEAST
STATUTE MILES
CONTOUR INTERVAL 30 FEET

to the base of the slopes. Valleys which form a continuation of submarine canyons and are generally attributed to turbidity currents show no tendency to stop along the slopes. In contrast, the Mississippi delta-front valleys do not extend far down the slope, which suggests another mechanism for their origin.

Furthermore, if turbidity currents were responsible for the valleys, they would be best developed directly outside the mouths of each of the principal distributaries. Figures 1 and 2, however, show no indication that the valleys are best or even well developed directly beyond the distributaries. For example, directly off the jetties of Southwest Pass valleys are very inconspicuous (Pls. 1, 2C), but to the southeast, where little muddy water would have impinged on the slope, valleys are well developed. Similarly, the best development of valleys around South Pass seems related to the flanks of the forward-moving delta front rather than to the distributary itself. The diagonal course of the large valley southwest of South Pass is also anomalous as turbidity currents are said to flow straight down slopes (Kuenen, 1953, p. 1297).

The presence of well-developed valleys off the old Grand Pass, which has now disappeared, and off the inactive Southeast and Northeast passes (Pl. 1) shows that an advancing slope is a more significant factor in producing the valleys than is the recent introduction of large amounts of muddy water into the area. Valleys caused by turbidity currents and related to passes would disappear off abandoned passes as the general slope grew forward.

The alternative hypothesis is that these delta-front depressions are slump valleys caused by some type of mass movement such as an earthflow (Sharpe, 1938, p. 50) in the fore-set slope. The very gentle inclination of the slope (as low as 0.75 per cent off Southwest Pass) might seem prohibitive of this hypothesis had not landslides been noted in water-saturated muds on slopes as low as 1 per cent (Ells, 1908). A sudden earthflow in the Lake of Zug in Switzerland in 1887 (Gilluly *et al.*, 1951, p. 237) left an underwater trench 20 feet deep and 1000 feet long. A debris tongue outside this flow is comparable to the fans outside the Mississippi Delta valleys.

The discontinuity of the valleys favors an earthflow, and their shifting position with time along the slope is equally favorable since the areas adjacent to a valley cut by landslides are likely to slide at some later time. The existence of mud lumps in front of the actively growing Mississippi passes has been explained by Morgan (1952, p. 138) as owing to plastic flow of the clay under the advancing bar of sandy silt.

The close relationship of angle of fore-set slope to the valley distribution indicates that the steeper slopes are unstable. As the delta builds forward, it evidently develops a slope which is greater than is compatible with the saturated clayey sediments. The valleys are best developed where the slope is slightly greater than 1 per cent off South Pass, and are concentrated on the relatively steep slope along the east flank of the bulge at Southwest Pass (Pl. 1), whereas they are very poorly represented on the gentler slopes to the west.

These considerations favor an earthflow or other type of landslide origin, although much of the displaced material may have continued down the slope, beyond the valley ends, as a turbidity current which was too weak to cut valleys.[4]

Relation to Origin of Deep Submarine Valleys

The evidence favoring an earthflow origin for the shallow valleys on the gentle slopes off the Mississippi Delta may apply also to the slightly incised valleys which extend down the slopes outside some major submarine canyons. (*See* Ericson *et al.*, 1951; Dill *et al.*, 1954; Menard and Ludwick, 1951; and Menard, 1953.) It has been suggested that these deep outer valleys could not be due to landslides since they are found on very gentle slopes, but this argument loses authority in view of the present study. Slides on the gentle slopes of the deep-sea floor could possibly account

[4] K. O. Emery has recently informed the writer of evidence that a series of similar sea-floor valleys off the Palos Verdes Hills in southern California are also due to landslides which continued seaward as turbidity currents.

for some of the curious valleys found in these places.

On the other hand, the shallow-valley continuations of the submarine canyons differ from the valleys off the Mississippi Delta. Sand is a common sediment on the floors of the former, and indicates strong currents. Furthermore, these deep outer valleys appear to slope continuously seaward in contrast to the short, discontinuous valleys bordering the Mississippi Delta.

The breaking of the cables during the Grand Banks earthquake has been attributed to turbidity currents by Heezen and Ewing (1952), who discarded a landslide hypothesis largely because the slopes seemed too gentle for landslides. The recent map of the outer cable-break area (Heezen *et al.*, 1954, Fig. 3), however, shows slopes of about the same inclinations as along the front of the Mississippi Delta. Furthermore, the mass movements indicated off the Mississippi Delta did not have the impetus of a large earthquake.

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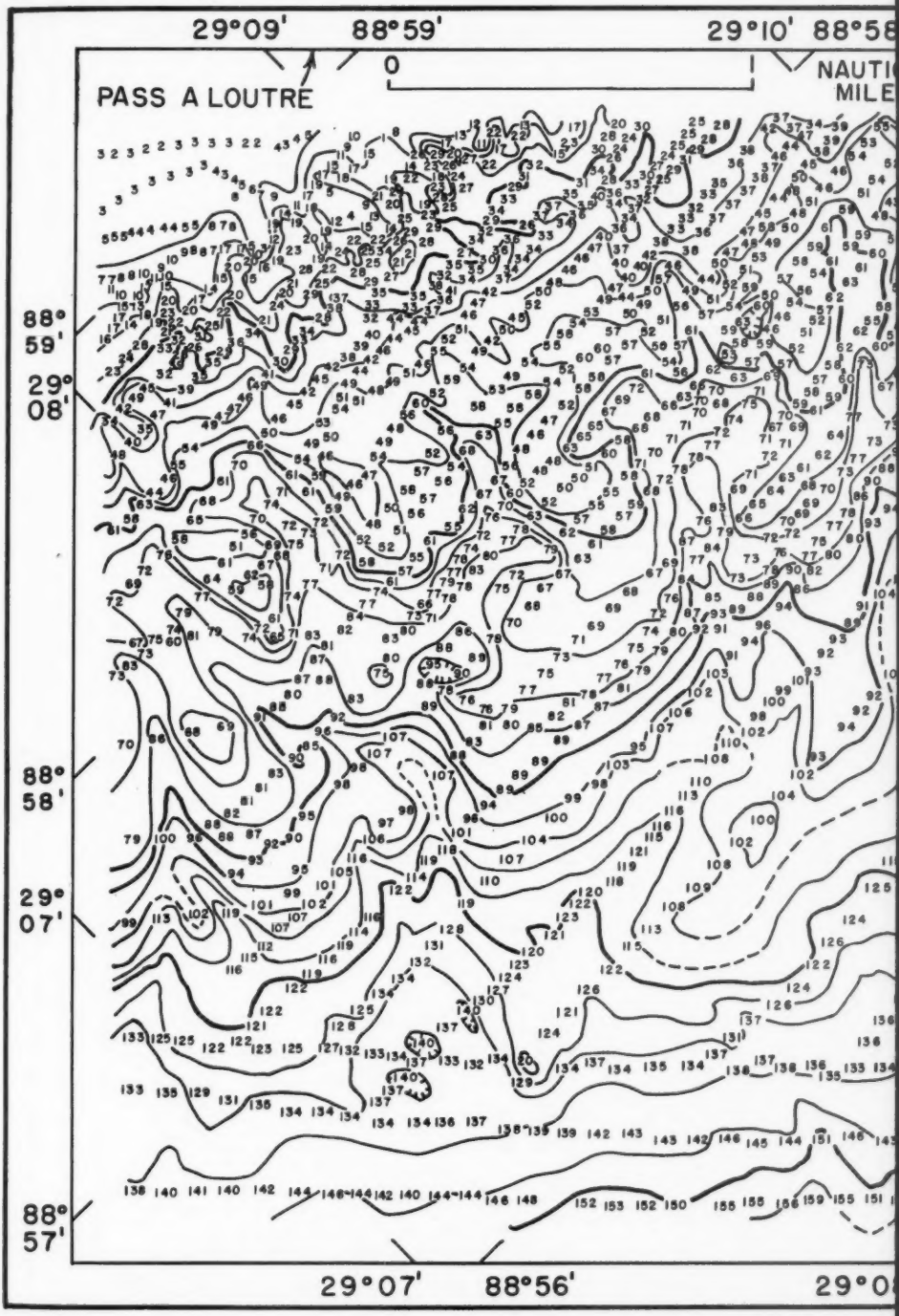
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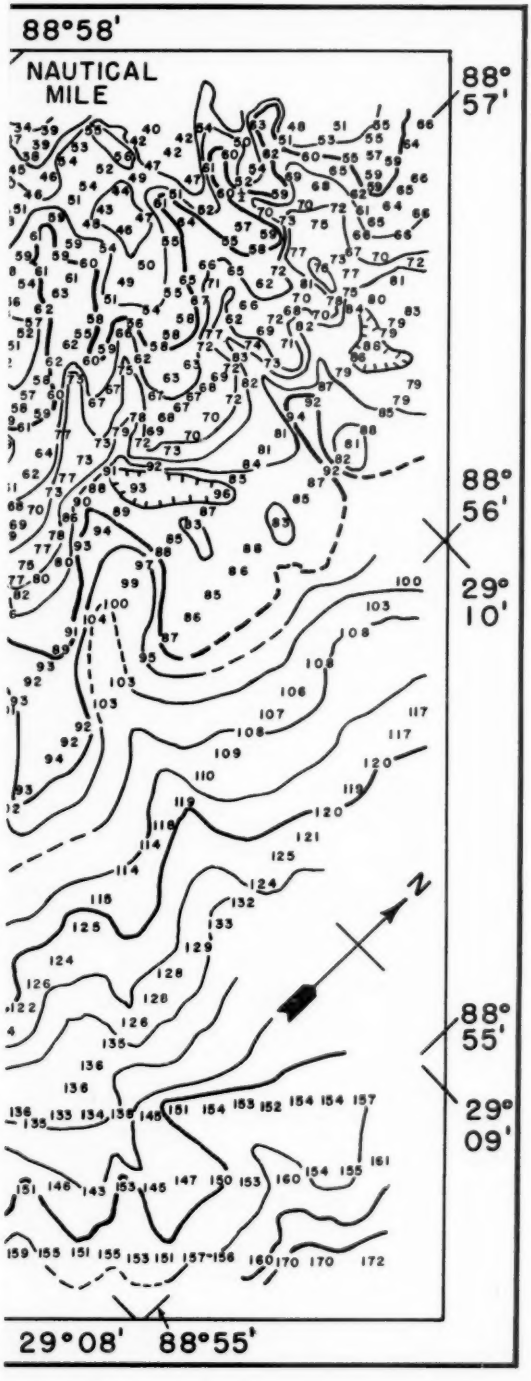

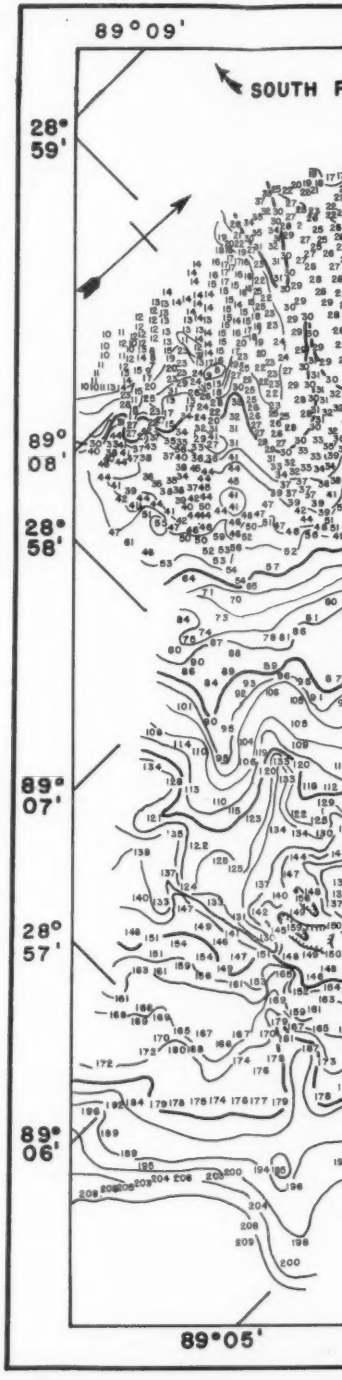

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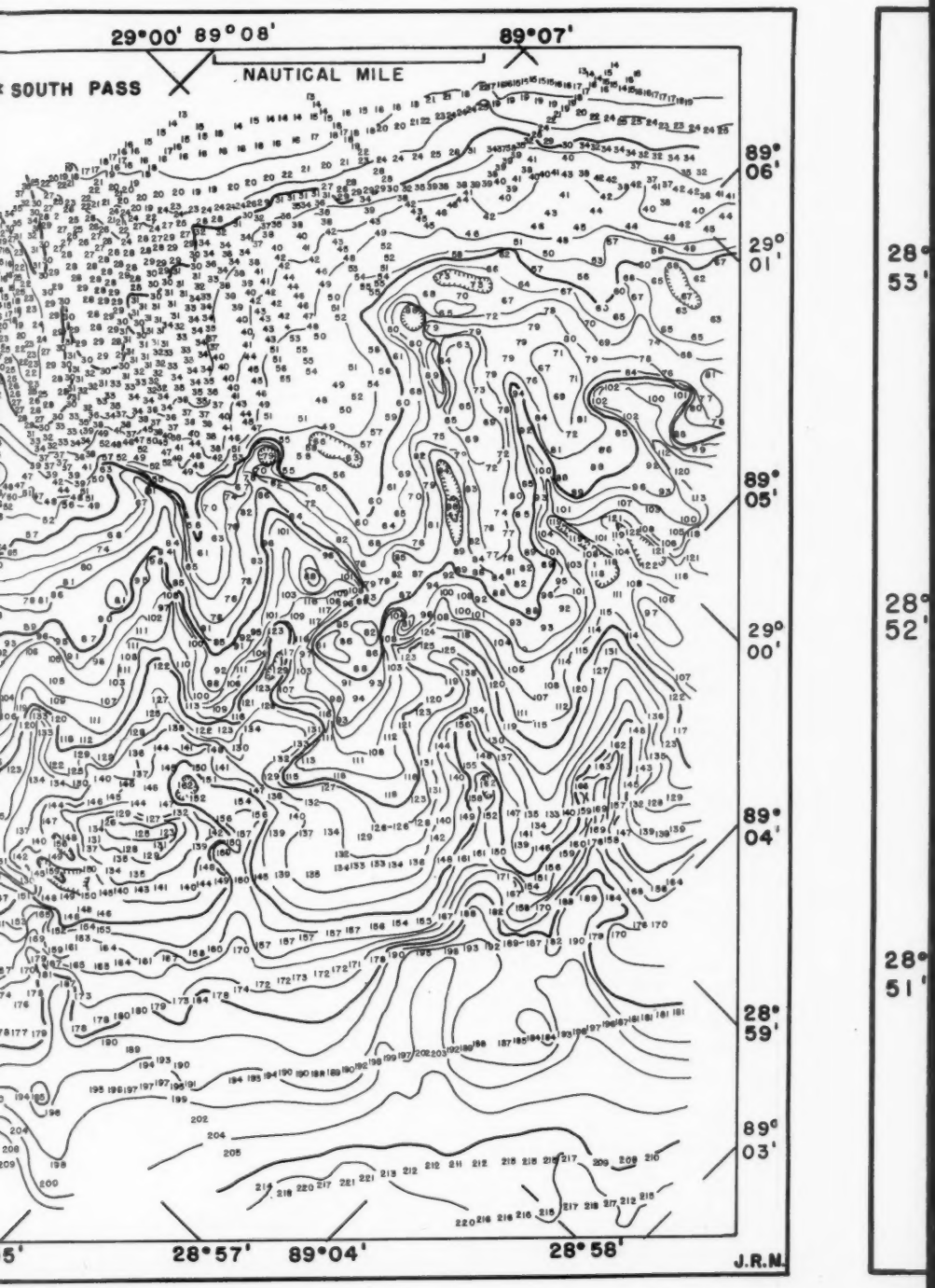

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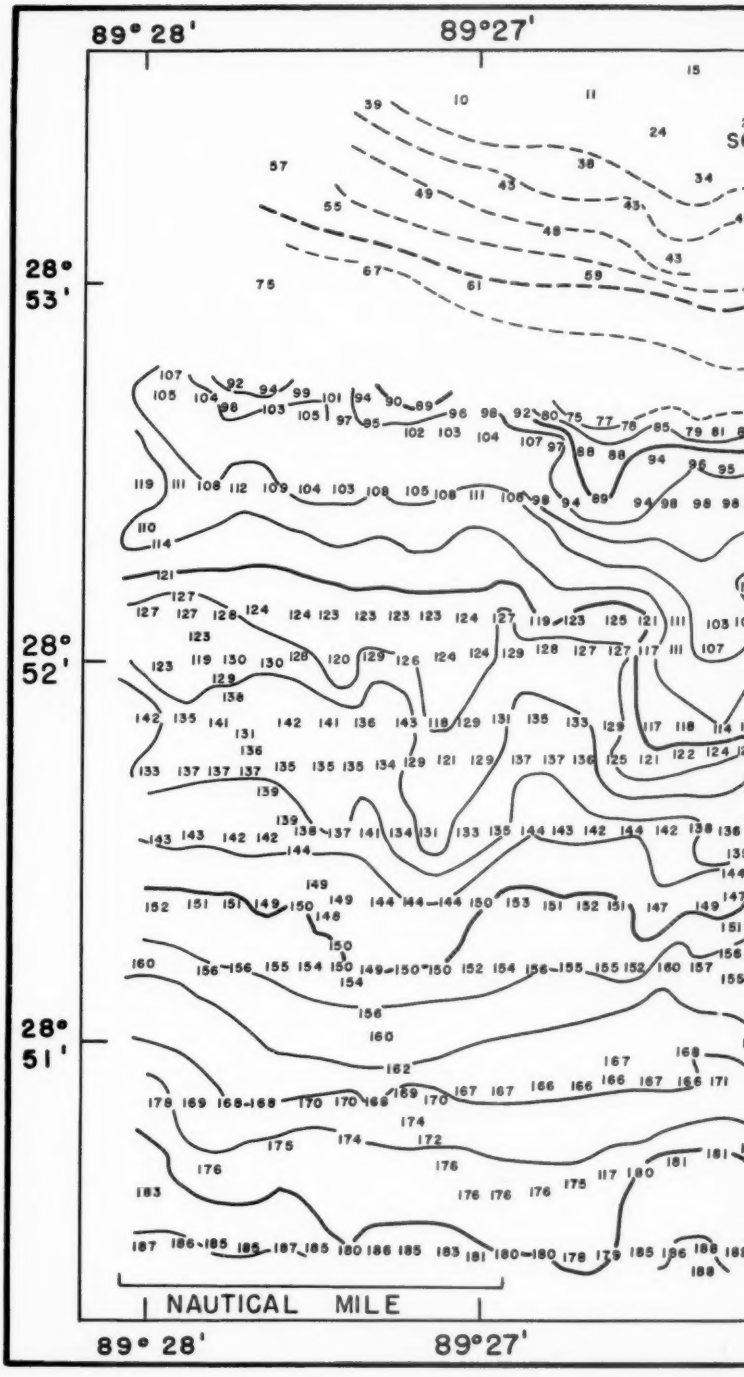

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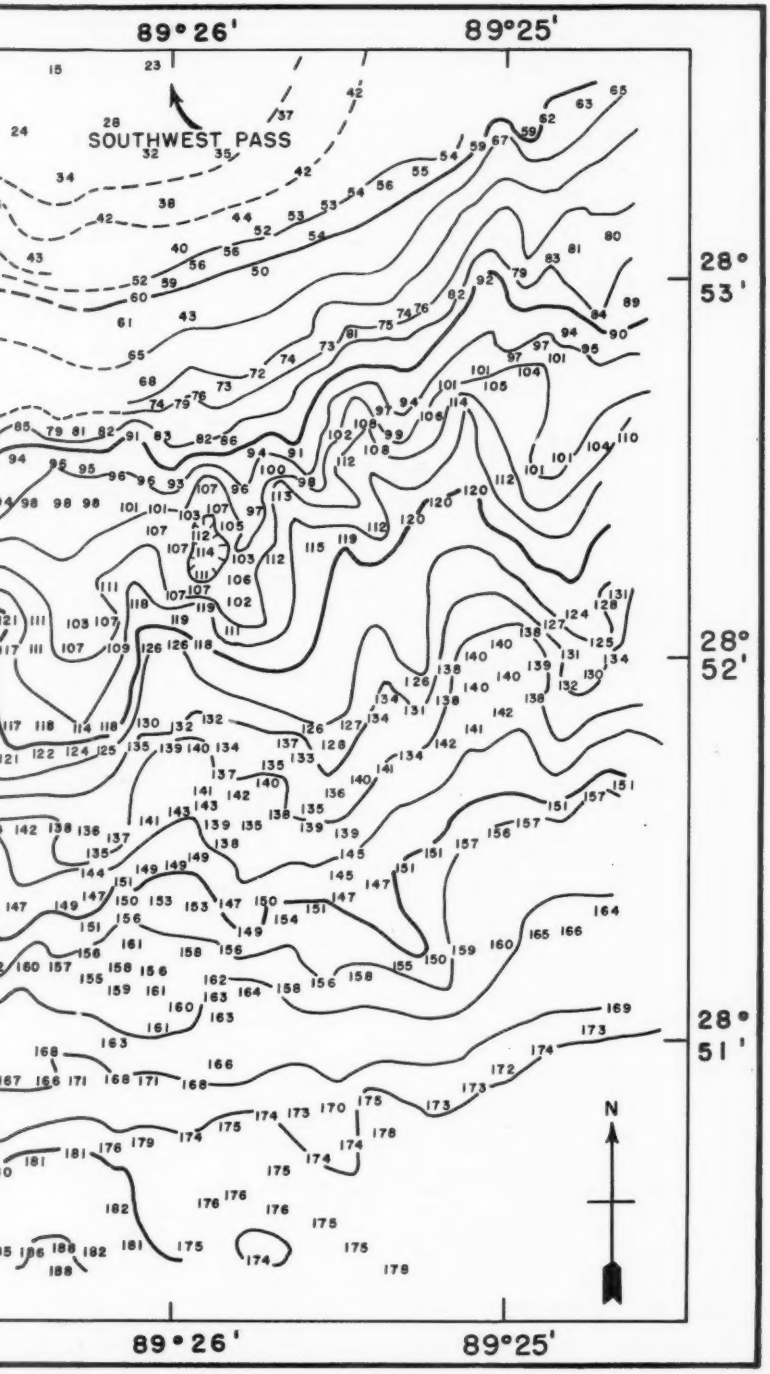
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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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BIOGEOGRAPHIC AND GEOLOGIC INDICATIONS OF UNGLACIATED AREAS IN SCANDINAVIA DURING THE GLACIAL AGES

BY EILIF DAHL

ABSTRACT

Biogeographers and geologists have disagreed about the extent and thickness of the ice shield during the last glacial age in Scandinavia. The relevant plant geographic data have been summarized. Presence of west arctic species otherwise lacking in Europe and western Asia, marked endemism, and the concentration of rare species in two separate areas of the Scandinavian mountains indicate that much of the present arctic-alpine flora has survived the last glacial age in refuges along the Scandinavian coast and adjacent mountains. Fossil records indicate that conditions in South and Central Sweden were not favorable for immigration from the south of much of this flora during the deglaciation period. Other fossil records indicate that arctic-alpine plants grew in the mountains immediately after deglaciation. Current geological methods for recognizing areas left unglaciated during the last glacial age in Scandinavia are considered. Unweathered erratics, glacial striae, etc., do not prove glaciation since they may have been deposited or formed during an earlier glacial age.

Some geologists believe that frost splitting in arctic and high alpine localities is so rapid that glacial striae and erratics could not survive a glacial age in Scandinavia. The rapid frost splitting is thought to be due to frequent shifts of temperature around 0°C or to severe frosts in winter. Available meteorological observations do not confirm that such shifts are any more frequent in arctic or high alpine localities than in the valleys and plains of North Europe. Strong weathering has also been observed in localities with no severe winter frost. In the Peruvian Andes where frequent shifts around 0°C occur, weathering differs from that observed in Scandinavian mountains.

The origin of mountain-top detritus, masses of large boulders weathered out *in situ* from the underlying rocks, is not completely understood. It probably has formed during a very long weathering cycle.

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INTRODUCTION

Pleistocene research is many-sided and draws information from geology, geophysics, climatology, soil science, biogeography, and many other fields. A series of papers on various aspects of Pleistocene research was compiled by members of the Committee of Interrelations

of Pleistocene Research (Flint, 1949). The biogeographic side of the question was well taken care of by Deevey (1949). From the biogeographic point of view Scandinavia has been particularly well studied, and problems connected with the nunatak theories have been discussed for more than 50 years by biogeographers and geologists. Unfortunately much of the information has not been available outside Scandinavia, and this paper presents an account of the problem, especially the botanical aspects.

Biogeographic conclusions are not always in harmony with geologists' points of view. The soundness both of biogeographic and geologic arguments must be considered. Current geologic methods may or may not be reliable in areas such as West and North Scandinavia. In any case some common beliefs underlying the present geologic approach, especially the belief that frost splitting is a rapid process in cold countries today, must be appraised.

The author is indebted to many geologists and botanists for stimulating discussions. Dr. Frank Mitchell, Trinity College, Dublin, Prof. R. F. Flint and Dr. E. S. Deevey, Yale University, have read the manuscript and offered valuable suggestions.

Age and Origin of the Scandinavian Arctic-Alpine Flora

Pleistocene Chronology in Northwestern Europe: The Tabula Rasa Theory

Let us remember that it is no more than 100 years since the scientific world began to accept the theory that ice once had covered major parts of North Europe, North America, and Siberia. First only one "Ice Age" was recognized, corresponding to the great deluge. Later multiple glaciations with cold glacial ages and warm or temperate interglacial ages were established. The sequence of events is particularly well known from the Alps, and at least four glacial ages have been recognized (Gunz, Mindel, Riss, and Würm). The Riss-Würm interglacial age is thought to have had a climate comparable to that of postglacial time but lasting about five times as long. The Mindel-Riss interglacial age lasted much longer, and the climate was possibly at times warmer than in postglacial time.

During the last glacial age in Scandinavia the ice advanced to a line across Jutland leaving the southwest corner of Denmark unglaciated (Fig. 1). In the unglaciated areas of Denmark and adjacent parts of Germany (Jessen and Milthers, 1928; Woldstedt, 1955) interglacial peats and fresh-water deposits are covered by solifluction gravels which indicate a colder climate. Two types of deposits belonging to this interglacial age have been recognized, the Herning and the Brørúp types (Jessen and Milthers, 1928). In localities with the Herning type there is evidence of an interstadial at the end of the interglacial age; in localities with the Brørúp type evidence of the interstadial is missing. The interglacial peats and muds contain macrofossils and pollen which shows that Norway spruce (*Picea abies*) was common in Denmark; spruce has not been native in Denmark since the last glacial age. The hornbeam (*Carpinus betulus*) was also a dominant component of the forests for a short time. The Carpinus zone is very helpful in the correlation of pollen diagrams from that age. Studies at the type locality of the Eemian marine transgression show that the Eemian sea is correlative with the interglacial stage of the Herning and Brørúp series (Gams, 1935); this is also true in Denmark (Jessen and Milthers, 1928, p. 179). Since the Eemian transgression is considered of Riss-Würm interglacial age, so are the Herning and Brørúp deposits. The climate of the interglacial, as indicated by macrofossils and pollen, was comparable to that of postglacial time.

Signs of glaciation, such as erratics, were recognized on the outmost islands along the Scandinavian coast before the end of the last century when the monoglacialist view still had wide support. This led to the conclusion that the entire Scandinavian peninsula had been covered by ice during the "Ice Age" and that, consequently, the entire flora and fauna had been destroyed. This, the *tabula rasa* theory (tabula rasa means blank table), proposed that the entire Scandinavian biota immigrated after the "Ice Age" from parts of Central Europe, England, and Siberia where plants and animals had been able to survive the glaciation.

Strong arguments support this theory. When compared with unglaciated areas, the biota of

Scandinavia has remarkably few endemics. The tabula rasa theory explained this as due to the youth of the flora and fauna; the time since the "Ice Age" had not been sufficient for the development of new species.

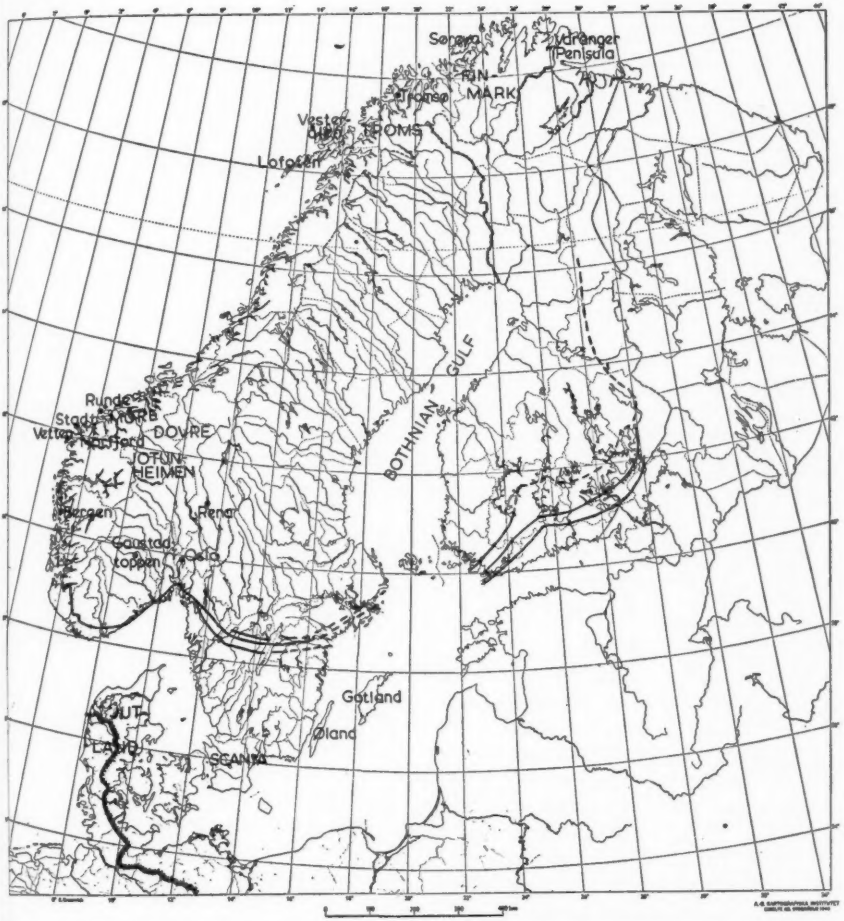

FIGURE 1.—KEY MAP OF SCANDINAVIA WITH THE LIMIT OF GLACIATION DURING THE LAST GLACIAL AGE IN DENMARK (after Milthers, 1942) AND ADJACENT PARTS OF GERMANY (after Woldstedt, 1955), AND THE RA-MIDDLE SWEDISH-SALPAUSSELKÄ MORAINES (after Holtedahl, 1953; Donner, 1951)

In South Scandinavia fossils of arctic and alpine[1] plants (*Betula nana*, *Dryas octopetala*, *Diapensia lapponica*, *Ranunculus hyperboreus*, *Salix herbacea*, *S. reticulata*, *Saxifraga oppositifolia*, *Thalictrum alpinum*) have been found in deposits formed under glacial conditions after the retreat of the inland ice of the last glacial age. When this was established, first by Nathorst (Nathorst, 1892; Anderson, 1906), the tabula rasa theory seemed to find its final confirmation. The presence of alpine and arctic elements in the Scandinavian flora, today isolated from similar elements in the Alps, in the Urals, and in the Arctic, could be explained by migrations along the borders of the waning ice of which the fossil finds bore witness.

[1] Alpine designates species which have their main distribution above timber line.

West-Arctic Element in the Scandinavian Flora: Amphiatlantic distributions

Some plant geographic facts remain, however, which are difficult to reconcile with the tabula rasa theory, especially the presence in Scandinavia of a west arctic element lacking in the Alps, Urals, and Asia but present in Iceland, Greenland, and North America (a few occur also in Novaya Zemlya and Spitsbergen). Examples are:

Antennaria porsildii
Arenaria humifusa
A. ciliata subsp. *pseudofrigida*
Braya linearis
Campanula uniflora
Carex parallela
C. holostoma
C. macloviana
C. nardina
C. rufina
C. scirpoidea
Draba crassifolia
D. norvegica (also in Britain)
Deschampsia atropurpurea
Epilobium lactiflorum
Erigeron unalaschkensis
Pedicularis flammea
Poa arctica subsp. *caespitans*
Potentilla chamissonis
P. pulchella
Puccinellia coarctata
Ranunculus lyngei
Rhododendron lapponicum
Sagina caespitosa
Stellaria calycantha

The west arctic element is also represented by numerous lichens and mosses.

It is difficult to explain the west-arctic element in the Scandinavian mountain flora by migrations from the south or east after the last glacial age. If these plants lived during the glacial age along the margins of the ice in Central Europe, why did they not migrate to the Alps? No similar west-arctic element has been found in the Alps; the species of the Alps have all their phytogeographic connections toward north and east (Professor Helmut Gams, personal communication).

Blytt (1881; 1893), who first drew attention to these problems, tried to explain them by postglacial transatlantic migrations. Sernander (1896) suggested that members of the west-arctic element in Scandinavia survived the last glacial age in refuges in West Norway, an explanation which has been supported by almost all biogeographers dealing with the problem (Hansen, 1904; Th. Fries, 1913; Wille, 1914; Smith, 1920; Nordhagen, 1931; 1933; 1935; 1936; 1937; Fægri, 1937; Nannfeldt, 1935; 1940; 1947; Kalela, 1944; Dahl, 1946; M. Fries, 1949; Selander, 1950; Bøcher, 1951; Melderis, 1953).

It has been pointed out that the west-arctic element in Scandinavia attracts attention because the range of the species of this element is restricted in Europe, but wide in America. The same applies to the American element in the British Isles (Heslop-Harrison, 1953); similarly some European species have a narrow range in eastern North America. Many species occur on both sides of the Atlantic, but only those of an assymetric type of distribution are selected for argument.

The foregoing introduces the problems presented by the amphiatlantic distribution of plants. As pointed out by Blytt (1881), Bøcher (1938), Nannfeldt (1940; 1947) Melderis (1953), and Piggott (1954) concerning vascular plants and by Dahl (1950) concerning lichens, the plant-geographic connections within the area comprising Greeland, Iceland, Scotland, and Scandinavia are so close that it is hard to avoid the conclusion that direct migration across the Atlantic has taken place. Hultén (1937) suggested that such species had migrated across the Bering Strait and subsequently died out in Asia and western North America, but he later seems to have modified his views (Nannfeldt 1947). It is improbable that the migration is postglacial, but how and when it took place is unknown. The species of a relict type of distribution not readily explicable in terms of ecology may be particularly helpful in informing us about the time of migration and may tell where the amphiatlantic species survived after the migration route was broken. The problems of the west-arctic element in the Scandinavian flora, the American element in the British Isles, the European element in eastern North America, as well as that of more symmetric amphiatlantic distributions are all different aspects of this major problem.

Immigrations from South and East during Deglaciation

Results of closer studies of the flora preserved in sediments formed in Scandinavia under glacial conditions support the survival theory. Remains of typical arctic-alpine plants

FIGURE 2.—DISTRIBUTION OF *Salix herbacea* WITH THE 26°C AVERAGE YEARLY MAXIMUM SUMMER TEMPERATURE ISOTHERM

After Dahl (1952). *Salix herbacea* common in shaded areas. Dots: outlying localities. Crosses and rings: localities of fossil occurrence of *Salix herbacea* outside its present range. Present and fossil occurrence mainly from Hultén (1950).

are plentiful in Denmark and southernmost Sweden but are unknown north of Scania (southernmost province of Sweden, Fig. 1) and Øland. This applies to *Diapensia lapponica*, *Oxyria digyna*, *Ranunculus hyperboreus*, *Salix herbacea* (Fig. 2), *S. myrsinites*, *S. reticulata*, *Saxifraga oppositifolia*, and *Silene acaulis* (Hartz, 1902; Gertz, 1917; Jessen, 1920;

Mathiesen, 1925; Hultén, 1950; Iversen, 1954). Farther north only *Dryas octopetala* (Fig. 3), *Betula nana*, and *Arctostaphylos alpina*, all species of distinctly less arctic-alpine character, have been found. The flora from deposits formed after the ice of the last glacial age had retreated north of the Middle Swedish moraines indicates that the areas left bare by the retreating ice were immediately invaded by a temperate flora in association with which the more typical alpine species had small chance of survival. Remains of *Dryas* have never been found in the lowlands north of the Middle Swedish moraines; the typical fossil in the glacial clays is *Hippophae rhamnoides* (Sandgren, 1943).

Studies of varved clays in Sweden suggest a rate of retreat of the inland ice north of Scania of 100–150 m per year; north of the Middle Swedish moraines the rate was up to 250 m per year. Such a rapid melting indicates a warm climate.

At the time of glacial retreat from south Scandinavia a climatic oscillation can be recognized in the stratigraphy and pollen profiles all over Northwest Europe. From a cold period (th Older Dryas period of South Scandinavia, zone I in the British Isles), the climate became warmer (the Allerød period of South Scandinavia, zone II in the British Isles) and again colder (the Younger Dryas period of South Scandinavia, zone III in the British Isles). The climatic deterioration during the Younger Dryas period led to a halt in the retreat of the Scandinavian ice shield or a readvance of the ice front represented by a belt of moraines (Fig. 1) from Finland (the Salpausselkä) through Sweden (the Middle Swedish moraines) and South Norway (the Ra) (Jessen, 1949; Donner, 1951). The younger Dryas period is approximately contemporaneous with the Mankato readvance in America (Flint and Deevey, 1951; Flint and Rubin, 1955; Flint, 1955). The interval comprising the Older Dryas, the Allerød, and the Younger Dryas periods (corresponding to the zones I, II, and III in the British Isles) is here called the late-glacial time (Iversen, 1947; Godwin, 1949; 1953; Charlesworth, 1953), and the time succeeding is here called the postglacial time and is equivalent to Antevs' (1953) concept of the neothermal age. This definition of late-glacial time is at variance with De Geer's (1925) original definition as his late-glacial also included the finiglacial time—*i.e.*, the time of glacial retreat from the Middle Swedish moraines to the mountains of Central Sweden which is estimated to have lasted about 1000 years. The distinction between De Geer's late-glacial and postglacial times cannot be made outside Scandinavia, whereas the distinction between late-glacial and postglacial times as defined here (according to Godwin, 1953) can be made over large areas.

Many alpine vascular plants cannot persist in areas with a high summer temperature. Isotherms of the average yearly maximum summer temperature at the highest points of the landscape coincide closely with the distribution limits of a large number of Scandinavian arctic-alpine species (Dahl, 1952). As an example may be chosen *Salix herbacea* (Fig. 2) with the corresponding 26°C isotherm. All species found as fossils north of Scania have a delimiting isotherm of 27°C or higher (*e.g.*, *Dryas octopetala*, Fig. 3), while a number of species found as fossils only farther south have a delimiting isotherm of 26°C or lower (*Salix herbacea*, *S. reticulata*, *Diapensia lapponica* at 26°C; *Silene acaulis* and *Saxifraga oppositifolia* at 25°C). One may therefore assume that the maximum summer temperature rose above 26°C when the ice retreated north of Scania and that species with a limiting isotherm substantially lower than 26°C could not migrate northward along with the ice (Dahl, 1952).

During the Younger Dryas period *Dryas octopetala*, *Arctostaphylos alpina*, and *Betula nana* lived in Sweden south of the Middle Swedish moraines. *Salix herbacea*, *S. reticulata*, *Oxyria digyna*, and *Saxifraga oppositifolia* survived in Denmark (Jessen, 1920; Iversen, 1954). These observations suggest a maximum summer temperature of 26–27°C over large areas of South Sweden—*i.e.*, around 3°C lower than at present. B. G. Andersen (1954, p. 338) found the snow line in Southwest Norway during the Younger Dryas period to be 400–550 m lower than at present, corresponding to a temperature depression of 2.8–3.9°C.

The rapid retreat of the ice north of Scania probably took place during the Allerød period. A considerable number of Scandinavian arctic-

alpine species that followed the ice died out (Nannfeldt, 1937); an additional number probably died out during the time of glacial retreat from the Middle Swedish moraines. At that time an arm of the sea, about 100 km broad, covered the land south of the ice margin with only a few scattered islands rising above sea level. This certainly added to the difficulties of survival of the arctic-alpine immigrants from the south (Nannfeldt, 1935; 1947; Nordhagen, 1937).

During deglaciation of the mountains of Central Norway and Sweden the snow line rose so high that no accumulation area was left. The inland ice became "dead", and consequently the summits melted out first. A study of the lateral moraines in the mountains (Mannerfelt, 1945; Holtedahl, 1953, p. 764 ff.) reveals that the last ice was left in the valleys and plains southeast of the mountains. This is confirmed by extensive terraces of ice-dammed lakes in the eastern valleys. When the last ice

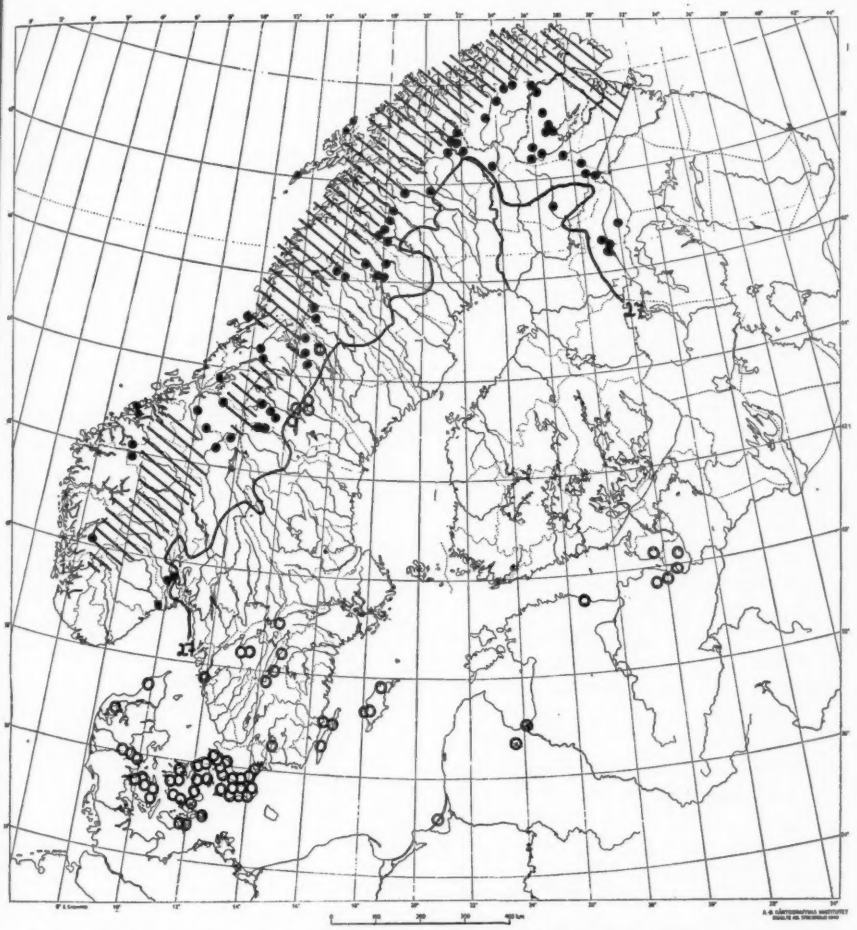

FIGURE 3.—DISTRIBUTION OF *Dryas octopetala* WITH THE 27°C AVERAGE YEARLY MAXIMUM SUMMER TEMPERATURE ISOTHERM

After Dahl (1952). *Dryas* common in shaded areas. Dots: outlying localities. Rings: localities of fossil occurrence of *Dryas* outside its present range. Present and fossil occurrence from Hultén (1950).

melted away the immigrant arctic-alpine plants from the south were still at least 100 km from the high mountains where they could find permanent refuge.

Remains of typical arctic-alpine plants have never been found in the lowlands of Central Scandinavia, but Smith (1916, p. 130) reports rich floras from deposits formed in lakes dammed by the waning ice in the Central Swedish mountains. The following list is taken from his publication:

Arctostaphylos alpina
Asplenium viride
Carex lachenalii
Diapensia lapponica
Dryas octopetala
Hippophae rhamnoides
Loiseleurea procumbens
Primula stricta (capsules)
Salix arbuscula
S. herbacea
S. reticulata
S. polaris (catkins and leaves)
Saxifraga oppositifolia
Thalictrum alpinum
Campylium stellatum
Catoscopium nigritum
Bryum ventricosum
Oligotrichum hercynicum

These plants indicate that a rich and varied arctic-alpine flora was present as soon as the higher mountains of Central Sweden became ice free. The discovery of *Primula stricta* and *Salix polaris* is of special interest since both species are absent in the Alps. *Salix polaris* has often been recorded from late-glacial deposits in South Scandinavia, but this is probably due to misidentifications (Nannfeldt, 1947).

These points influence the concepts regarding the happenings in America at the end of the last glacial age. In marked contrast to the frequent occurrence of a late-glacial *Salix herbacea-Dryas* flora in Europe is the scarcity of similar finds in North America. Dr. Frank Mitchell, Trinity College, Dublin, has kindly drawn attention to the fact that there are some discoveries of such plants in glacial clays in America (Emerson, 1898; Tarr, 1909; Hollick, 1931), but such deposits are undoubtedly more scarce in America than in Europe. During deglaciation, the climate must have been quite warm, at least at times. In marked contrast to North Europe, it has been difficult to establish any tundra phase in the vegetational history of North America after the Wisconsin age. Thus far, only a few pollen diagrams from northern Maine (Deevey, 1951) and from Ontario (Ignatius, unpublished) show such a phase. S. T. Andersen (1954) suggests the existence of a tundra with scattered trees in Michigan in late-glacial times; a safe interpretation of his pollen diagram is, however, difficult because of presence of rebedded pollen. Deglaciation following the Mankato subage was rapid (Flint, 1955), and, judging from the fauna, the headwaters of the rivers formed just after the retreat of the ice must have been quite warm (Deevey, 1949, p. 1394). The difficulties in explaining how an arctic-alpine flora could follow the retreat of the ice in South and Central Scandinavia are certainly no less in central and eastern North America. This leaves an open question concerning the origin of the arctic-alpine flora of eastern North America if some sort of nunatak theory cannot be accepted.

Hitherto the question of immigration of the Scandinavian mountain flora from the east has not been considered. Unfortunately there is much less information about conditions during glacial and late-glacial times in the east than in the south of Fennoscandia. Hence reliance must be placed upon more indirect evidence. The Middle Swedish moraines have their continuation in the Salpausselkä moraines in Finland, and conditions during deglaciation after the Salpausselkä stage correspond closely to contemporaneous conditions in Sweden. It is not known when a possible migration route from the east was opened. Clearly the Scandinavian mountain flora has been enriched with species from the east. In North Scandinavia there is a characteristic Siberian element; the species have a continuous distribution eastward. Most of the Siberian plants are, however, not arctic-alpines but may live in forest regions as well. It is difficult to believe that the west-arctic element immigrated this way. Some of the west-arctic species (*e.g.*, *Carex rufina*) have a pronounced oceanic character and avoid the continental parts of the Scandinavian mountain range. Some species with eastern affinities exhibit enormous gaps in the distribution: *Crepis multicaulis* and *Oxytropis deflexa*, for instance, have their nearest localities east of Baikal (Nannfeldt, 1935; Selander, 1950).

Endemism in the Scandinavian Flora

Although the Scandinavian flora is remarkably poor in endemic species, there is a difference between the alpine and the lowland floras. There are a number of endemic alpine species, *viz*:

Alchemilla oxyodonta
Arnica alpina
Draba cacuminum
Euphrasia hyperborea
E. lapponica
Papaver lapponicum
P. laestadianum
P. relictum
Primula scandinavia

Species of polymorphic apomictic genera (*Hieracium*, *Taraxacum*, *Sorbus*) are not included in these enumerations.

In addition, a number of endemic subspecies occur, such as:

Draba hirta ssp. *dovrensis*
Galium pumilum ssp. *Normani*
Melandrium apetalum ssp. *typicum*
Papaver radicatum ssp. *hyperboreum*
P. radicatum ssp. *macrostigma*
P. radicatum ssp. *ovatilobum*
P. radicatum ssp. *subglobosum*
Stellaria crassipes ssp. *dovrense*
Viola rupestris ssp. *relicta*

The lowland flora, comprising many more species, has few endemic species. *Helianthemum oelandicum* in the island of Øland was probably widespread in late-glacial time (Iversen, 1947) and is now a relict; *Viscaria alpina* v. *oelandicum*, *Galium pumilum* ssp. *oelandicum*, and *Pulsatilla vulgaris* ssp. *gotlandica* have similar distribution types. *Deschampsia bottnica*, *Euphrasia bottnica*, and *Artemisia borealis* ssp. *bottnica*, all halophilous species growing along the shores of the Bothnian Gulf, seem to present a problem of their own for they grow within the now-restricted range of the formerly widespread *Hippophae rhamnoides*. Pollen of an unidentified *Artemisia* is abundant in the late-glacial deposits of Northwest Europe. *Centaurium glomeratum* is restricted to Scania, *Agropyron caninum* ssp. *muticum* and *Galium pumilum* ssp. *suecicum* to South Sweden. *Saxifraga osloensis* (Knaben, 1954) in Central Scandinavia has probably arisen through a spontaneous crossing between two other species in postglacial times. *Geum hispidum* in southeast Sweden is probably a neo-endemic now rapidly spreading (Hultén, 1950).

If the arctic-alpine element migrated from the south and east to the Scandinavian mountains in late-glacial and early postglacial times, the arctic-alpine and the lowland elements are of approximately the same age in Scandinavia. The relatively large number of endemic species in the arctic-alpine flora presents a serious problem if this is so. If, however, much of the alpine flora survived the last glacial age in refuges along the Scandinavian coast, the large number can be explained as being due to the greater age of the arctic-alpine element.

Bicentric and Unicentric Distributions

We now consider whether biogeography can indicate locations of the refuges where arctic-alpine biota might have survived the last glacial age. In the refuges, or in the neighborhood, one might expect to find a concentration of rare plants. Two areas are immediately singled out because of their special flora—one in South Scandinavia in the Dovre-Jotunheimen mountains and the other in North Scandinavia from the polar circle northward to Troms and Finmark. A great number of species are confined to these areas, among them many west-arctic and endemic species.

Blytt (1876) tried to explain this fact in terms of ecology. Many of the species restricted to the two areas are calcicoles, and good localities for calcicoles are found in these areas. The localities with the richest floras are east of the high mountains of the Scandinavian mountain range. Blytt suggested that the rare species were of a continental character shying away from the cold summers, warm winters, and heavy precipitation of the more oceanic areas. He emphasized especially the importance of conditions in spring. Many alpine species do not survive in botanic gardens unless covered in winter since they otherwise sprout too early and are killed by late frosts. Blytt believed that many alpine species could be killed in a similar way in nature. Bøcher (1951) pointed out that the ranges of some of the rarer alpine plants in Scandinavia are inverse to those of oceanic species. Finally, the mountains of Trøndelag and adjacent areas of Sweden are much lower than the mountains farther north and south.

This may explain the disjunct distribution of many species in the Scandinavian mountains (Arwidsson, 1943). If maximum summer temperature is a measure, Figure 4 shows that all species restricted to areas with summer temperatures below 22°C must be absent from the intermediate region (Dahl, 1952).

Whether the ecologic factors mentioned can explain the distribution of the arctic-alpine species is a question. Th. Fries (1913) believed the distribution had to be explained in terms of historical factors. He suggested two refuge areas in Scandinavia during the last glacial age, one on the coast of Møre northwest of Dovre, another from the Lofoten islands northward. The species restricted to the Dovre-Jotunheimen mountains and the mountains north of the polar circle were explained as survivors from the last interglacial age, which during late-glacial and postglacial times had migrated into the adjacent mountains. He coined the term bicentric to denote the distribution of species restricted to both these areas; later Arwidsson introduced the term unicentric to denote the distribution of species confined to one of these areas. There is a northern and a southern unicentric element.

The following have a bicentric type of distribution:

Poa arctica
Carex parallela
C. arctogena
C. bicolor
C. misandra
Luzula arctica
L. parviflora
Nigritella nigra
Stellaria crassipes
Cerastium arcticum
Sagina caespitosa
Minuartia rubella
Melandrium apetalum
Ranunculus hyperboreus
R. platanifolius
Papaver radicatum
Draba cacuminum
D. fladnizensis
D. lactea
Braya linearis
Saxifraga aizoon (aberrant type)
S. hieraciifolia
Rhododendron lapponicum
Euphrasia lapponica
Campanula uniflora

The following species occur in North Scandinavia, but there is a gap between the range in Scandinavia and the nearest localities outside Scandinavia. They thus belong to the northern unicentric element.

Woodsia glabella
Trisetum subalpestre
Scirpus pumilus
Carex scirpoidea
C. nardina
C. macloviana
C. holostoma
Platanthera oligantha
Arenaria humifusa
A. ciliata ssp. *pseudofrigida*
Ranunculus lyngei
R. sulphureus
Papaver laestadianum
P. dahlianum
Draba crassifolia
Braya purpurascens
Potentilla chamissonis
P. emarginata
P. multifida
P. pulchella
Oxytropis deflexa
Cassiope tetragona
Gentiana detonsa
Polemonium boreale
Pedicularis flammea
P. hirsuta
Erigeron unalaschkensis
Antennaria carpathica
A. porsildii
Arnica alpina
Crepis multicaulis

The following species belong to the southern unicentric element

Phippsia concinna
Stellaria crassipes ssp. *dovrense*
Papaver relictum
Draba hirta ssp. *dovrense*
Pedicularis oederi
Artemisia norvegica

The main soil factor involved in the distribution of alpine plants appears to be the degree to which the humus colloids are saturated with cations, predominantly calcium ions. There are no indications that the local occurrence or the general distribution of any alpine species is determined by more specific factors such as amount of potassium or phosphorus or micronutrient salts available, except for a limited number of species associated with magnesium-rich soils or with copper ores (Rune, 1953). Many of the interesting species are calcicoles, and one of the most typical is *Dryas octopetala*. Judging from the distribution map of *Dryas* (Fig. 3) the localities for calcicole species are not confined to the areas of centric plants.

In many cases the summer temperature may be a contributing factor (*e.g.*, *Campanula uni-*

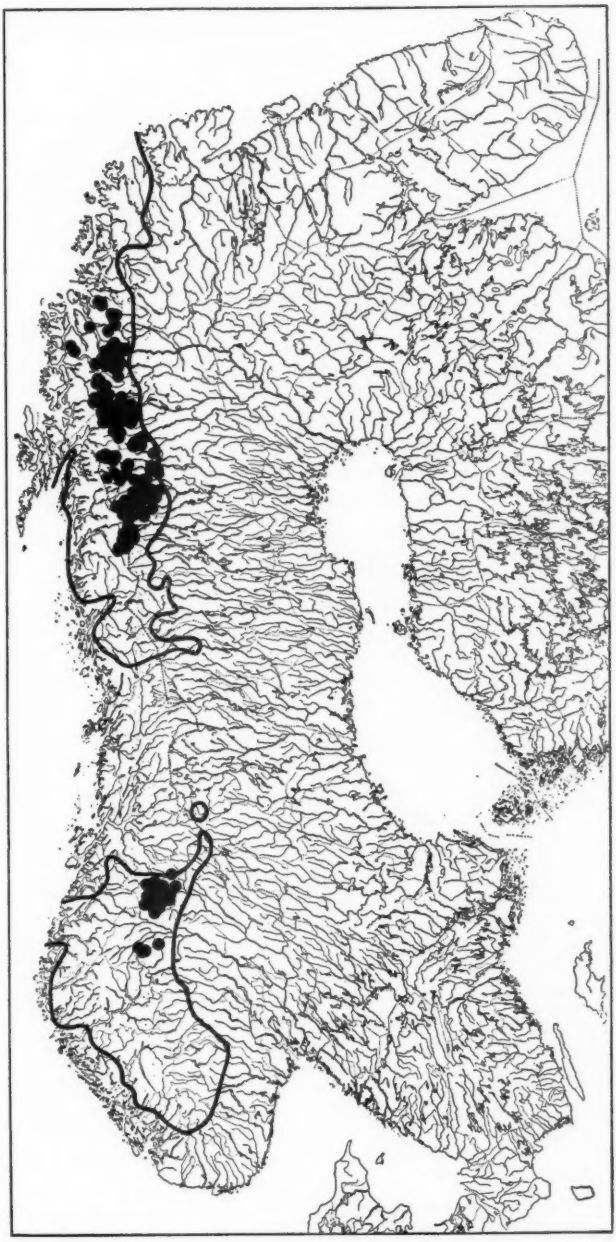

FIGURE 4.—DISTRIBUTION OF *Campanula uniflora*, A BICENTRIC SPECIES, (after Arwidsson 1943) WITH THE 22°C AVERAGE YEARLY MAXIMUM SUMMER TEMPERATURE ISOTHERM

After Dahl (1952)

flora), but the distribution of a number of alpine centric species cannot be explained that way. Many bicentric species like *Ranunculus platanifolius*, *Luzula parviflora*, and *Nigritella nigra* (represented in Scandinavia by a race differing from that of the Alps among other things by a different chromosome number) are subalpine species which insofar as requirements to low summer temperature are concerned might well live along the whole mountain range.

The suggestion that the continentality of centric species is important was more impressive in Blytt's time than today. Closer investigations have revealed that many of these species occur much closer to the ocean than known by Blytt. Most of the species ocurring in the southern area are also found in the Trollheimen Mountains northwest of Dovre, with no higher mountains farther west and with considerable precipitation. *Saxifraga hieraciifolia*, *Pedicularis oederi*, and *Euphrasia lapponica* have been found close to the coast. In the north, numerous species grow to the coast, indicating that continentality is no delimiting factor.

Of course it cannot be proved that the distribution of the centric species is not determined by present-day ecological factors. More information on the ecology of alpine species is needed. But even if it were possible to relate the distribution of all Scandinavian alpine species to ecological factors, several questions would still remain.

If ecologic conditions account for the distribution of the centric species, it is evident that they can persist only within a narrow range of ecologic conditions. This is in marked contrast to the behavior of the same species in other areas where they occur over wide areas and in a series of different vegetation types (*e.g.*, *Rhododendron lapponicum*, *Poa arctica*, *Carex scirpoidea*, *Saxifraga aizoon*). This discrepancy might be explained if the populations in question are relicts which have survived in a small refuge. If the population was once small it would have been depleted of genes and hence of variability (*see e.g.*, Dobzhansky, 1947, p. 331 ff). The population would become less adaptable to new conditions, in itself an indication of a relict.

Species able to migrate over considerable distances behind the retreating ice despite vicissitudes during later phases of deglaciation must have good spreading ability and be able to persist over a considerable range of ecologic conditions. Most centric plants show little adaptation to rapid spreading, and the populations are very stable from year to year.

A closer examination of certain species or groups of species bears out their relict character. Isolation is commonly followed by morphological differentiation. Nordhagen (1931) showed that *Papaver radicatum* s.l. in Scandinavia consists of a number of distinct species and subspecies, some endemic, others of a wide range. Nannfeldt (1940) investigated *Poa arctica*, most forms of which are apomictic, and found several distinct subspecies, some of a wider range (Greenland, Iceland, the Arctic), others apparently endemic. The southern population of the bicentric *Stellaria crassipes* forms its own endemic subspecies *dovrense*. It grows in a small group of the Dovre Mountains and is not known to set seeds.

As more details of the distribution of the Scandinavian alpine plants are learned, the problem becomes more puzzling. Within the centric species of South Norway, different distribution patterns may be recognized. Some are confined to the Dovre-Trollheimen Mountains (*Artemisia norvegica*, *Campanula uniflora*), others to the Jotunheimen Mountains (*Rhododendron lapponicum*, *Braya linearis*). Perhaps valleys have been sufficient obstacles to the spreading of such species.

Survival of a considerable part of the Scandinavian arctic-alpine flora through the last glacial age in refuges along the Norwegian coast and adjacent mountains could explain many of the above problems. The biogeographer is faced with an unpleasant number of difficult problems if this possibility is denied.

Geologic Methods and Evidence of Unglaciated Areas in Scandinavia during the Last Glacial Age

The biogeographic evidence indicates that there may have been refuges of arctic-alpine plants during the last glacial age in the Møre area, West Norway, and from the Lofoten Islands northward in North Norway, perhaps with subsidiary refuges elsewhere.

The biogeographic evidence is indirect, as it is inferred from the present-day distribution that some species survived glaciation. Biogeographic methods hardly permit an exact location of the refuges; the plants have migrated since, and postglacial history certainly has influenced their distribution patterns. By geologic methods it is perhaps possible to point out the actual ice-free areas.

However, geologic methods may also give only indirect evidence. Even if all the land surface had signs of glaciation dating from the last glacial age we could not, as pointed out by Farrington (quoted from Jessen, 1949), conclude that plants and animals could not have survived somewhere in the area. Ice would have to cover the entire area at one time to warrant such a conclusion. The inland ice of the last glacial age reached its maximum extent at different times in different areas in a way termed metachronous by the Russians (Gerasimow and Markow, 1939). It must also be proved that the signs of glaciation assumed to date from the last glacial age are not survivors of an earlier glacial age.

The survival hypothesis received immense support when Vogt (1913), after investigations in the Lofoten Islands, concluded that some of these islands had not been totally glaciated during the last glacial age. On the flat summits of some of these islands extensive boulder fields lack erratics. Vogt therefore concluded that they had not been overridden by ice. Later authors (Ahlmann, 1919; Strøm, 1938; Grønlie, 1940) support his views. Oxaal (1915) concluded that the island of Træna south of Lofoten escaped glaciation. Undås (1938) assumed that some areas on the outer coast of Vesterålen and West Finmark were unglaciated and suggested the existence of refuges during the previous glacial ages too. Nordhagen (1940) has drawn attention to the peculiar weathering forms found on the west side of Sørøya, West Finmark, and in other localities along the northern coast; he suggested that they were the result of interglacial weathering. He is supported by Linton (1949). Some submarine moraines described by Holtedahl (1929a) from outside the fjords of the Varanger peninsula have (Holtedahl, 1929b, p. 159; Nordhagen, 1933, p. 73) been interpreted as belonging to the maximum advance of ice during the last glacial age.

In the case of Møre, Reusch (1910, p. 160) already had suggested that the outer part of the Romsdals fjord was unglaciated during the last glacial age. This is an area where signs of glaciation are very much in evidence, though less so than farther inland. Kaldhol (1930; 1946; 1951) advocated that parts of Møre escaped glaciation during the last glacial age and also during earlier glacial ages. Hitherto he has not had much support from other geologists, although Dahl (1948) supports some of his views. Undås (1942a) also believed that some small areas on the coast of Møre escaped glaciation during the last glacial age.

Geologists are divided on these issues. Tanner (1937; 1944) who was the champion of total glaciation pointed out that erratics may have been destroyed during late-glacial and postglacial times owing to vigorous frost splitting and erosion. Weathering forms similar to those of allegedly unglaciated areas are also found in localities believed to have been glaciated during the last glacial age. Holtedahl (1953) is also sceptical of the survival hypothesis. According to him trough-shaped depressions on the continental shelf indicate that glaciers advanced far beyond the Norwegian coast. However, similar depressions are also found on the floor of the unglaciated British Channel (Dahl, 1955).

First of all the tools must be examined to make sure that the methods available are likely to give an answer to the questions. Several glaciations must be considered; the last glaciation in North Europe was not the most extensive. The ice shield of the last glacial age did not cross the North Sea as did one of the earlier. In other parts of North Europe and in North America the penultimate glaciation extended farther than the last. It is therefore likely that the same applied to Norway. Areas overridden by an older glaciation but left ice free during a later glaciation may still have marks from the older, and the problem is then how to distinguish evidences of glaciation dating from different glacial ages.

At least some nunataks were ice free during the last glacial age. In West and Northwest Norway the relief is very pronounced; high

mountains are close to the deep ocean. On account of the plasticity of the ice, it is difficult to imagine how such an area could be totally glaciated under such meteorological conditions as may have existed. Under present-day conditions such areas are not totally glaciated, not even in Antarctica. (For further particulars *see* Dahl, 1946; Holtedahl, 1929b, p. 28.) There should be a zone in the mountains and perhaps along the coast overridden by the ice shield during an earlier glacial age but left ice free during the last. Perhaps areas unglaciated during the whole of the Pleistocene may be found.

Some of the methods which give excellent results along the border of the Pleistocene ice shields farther south do not yield much in West and North Scandinavia. In areas with a very youthful topography the rivers are rapidly eroding along their whole courses; consequently methods associated with deposition of river gravels and clays are not promising. There are no extensive loess sheets; in humid climates such phenomena are less prominent than in arid climates. Implements from human settlements are scarce, and, since it is a border-line area, the implement types cannot be equated in time with similar industries farther south.

Interglacial deposits covered by glacial drift are not so rare in level landscapes with extensive and continuous drift sheets as in Central Europe. However, in a rugged landscape, such as West Norway, the drift is patchy and varies immensely in thickness over short distances. The chances of finding interbedded interglacial deposits in West and North Norway are much poorer than farther south, and this probably accounts for the scarcity of records. One certain interglacial or interstadial deposit is known from near Bergen (Undås, 1942b), another from near Tromsø (Grønlie, 1940), besides a number of more questionable ones. However, at the present stage of knowledge it is unwise to draw conclusions from the absence of finds of interglacial deposits.

Conclusions regarding conditions during the maximum extent of the ice of the last glacial age are also inferred from the study of raised beaches. If the relative position of land and sea at different periods is known, the raised beaches can be dated. Students of raised beaches try to infer the relative position of land and sea from the occurrence and appearance of the raised beaches. This necessarily involves circular reasoning, and the utmost care, and support from other methods, are required for valid conclusions.

Some geologists have attempted to draw conclusions from the degree of weathering of the boulders. Boulders found along the southern boundaries of the Pleistocene ice sheets and dating from older glacial ages are often recognizable by a difference in the degree of chemical weathering from those deposited during the last glacial age. Attempts have been made to apply the same methods in more northern countries. The scarcity of conspicuous weathering crusts is taken as an indication that all moraines and erratics date from the last glacial age. However, this is hardly a safe conclusion. Rates and degrees of weathering in regions with very different climates are compared, but climate influences the weathering immensely. The conclusion is defensible provided one can be sure that a conspicuous weathering crust was formed during the last interglacial age and that the crust was subsequently preserved.

By chemical weathering, ions are removed from the minerals of parent material under the influence of rain water and substances dissolved in the water, and new minerals, called clay minerals, are formed. The main rock-forming minerals of the Scandinavian mountain range are quartz, mica, and feldspars. Quartz is practically insoluble in temperate and cold climates. From the micas, potassium can be removed under climatic conditions prevailing in Scandinavia today (Goldschmidt and Johnson, 1922), and illite is formed. In warmer climates the process probably proceeds to kaolin or montmorine (montmorillonite isomorphous series, montmorillonoids of MacEwan *in* Brindley, 1951). Chemical weathering of feldspars yields kaolin or montmorine. The parent material changes to a whitish, clayey crumbly powder. The visible weathering of boulders and the formation of gumbotil are probably due to this process.

The studies of Soveri (1950) and earlier authors have shown that late-glacial and postglacial clays of South and Central Fennoscandia normally contain no appreciable quantity of

kaolin and montmorine, but consist mainly of fine-grained quartz and feldspar with illite. Some clays from southernmost Sweden contain kaolin or montmorine probably derived from Mesozoic rocks or from the preglacial weathered crust. The preglacial weathered crust is also thought to have contributed montmorine to some clays near the ice divide of the last glacial age where glacial erosion has been less intense. The conclusion is that weathering of rock minerals to kaolin or montmorine is very slow under conditions prevailing in South and Central Scandinavia during postglacial times.

This explains why no conspicuous weathering crust has formed during postglacial times in Scandinavia. Since climatic conditions during the last interglacial age were not different from those of postglacial times, and since this interglacial was of a similar order of magnitude, there is no reason to expect that any conspicuous weathering crust formed during the last interglacial age. Furthermore, a weathering crust is easily removed by moderate frost splitting and is not preserved if unprotected against frost splitting.

Some geologists have concluded that glacial striae prove glaciation during the last glacial age. They argue that glacial striae formed during the penultimate glacial age could not possibly survive conditions on nunataks or ice-free forelands in Scandinavia during the last glacial age. Since striae are widespread along the Norwegian coast (though rare in some areas), this has been taken to support the tabula rasa theory.

Striations on rocks exposed to the atmosphere are, in time, obliterated by weathering. Some protection (either by water or by sediments) is necessary for the preservation of striae over long periods.

It is believed that the last glacial age started by ice accumulations in the mountains, particularly along the coast in West and North Norway where glaciers are found today (Flint, 1943; Holtedahl, 1953, p. 589). The increased load of ice undoubtedly led to isostatic subsidence, and the shores became submerged. In Scandinavia the isostatic subsidence during the last glacial age was greater than the eustatic lowering of sea level. Consequently striations near sea level became protected from the atmosphere. In Norwegian coastal areas, ice free during the last glacial age, striae of the penultimate glacial age could probably have survived near sea level.

It might be argued that one would not expect to find unglaciated areas during the last glacial age where conditions for accumulation of ice are so favorable as to permit the existence of glaciers today. This, however, does not necessarily follow. The landscape is cut by deep fjords where the excess accumulation of ice during the last glacial age could find its outlet through calving glaciers.

During the penultimate glacial age drift was undoubtedly deposited in West and North Norway, and this protected the striae on the underlying rocks. During the last interglacial age, interglacial deposits were undoubtedly formed in many places. The striae from the penultimate glacial age could not have been destroyed before removal of the protective sediments. The striae might be destroyed by chemical or mechanical weathering. Rain and substances dissolved in the rain change the chemical composition of the uppermost part of the sediments thus forming a soil profile. The thickness of the soil profile formed during postglacial times in Scandinavia may be a few feet. Farther down the sediments are very little altered, and the striations on boulders in the boulder clays are preserved. The soil profile of the last interglacial was hardly of a different order of magnitude judging from known profiles elsewhere in Europe (Zeuner, 1952) or in North America (Flint, 1947).

Temperature fluctuations crossing 0°C are necessary for destroying striae by frost splitting. Such fluctuations do not penetrate very far down in sediments. Consequently, removal of the protective sediments is necessary for destruction of striae in this way.

Thus, as long as some of the drift from the penultimate glacial age and some deposits of the last interglacial age are intact, there will be a chance of finding striae and erratics from the penultimate glacial age. If it is assumed that glacial striae or erratics from the penultimate glacial age could not survive in possibly ice-free refuges during the last glacial age in West and North Norway, then there will be little chance of finding drift from the penultimate

glacial age or interglacial deposits from the last interglacial age in the refuges. If so, current geological methods are useless in proving existence of unglaciated areas.

The idea that old glacial striae may be preserved through subsequent glacial ages is clearly expressed in Blytt's classical treatise (1876, p. 71):

> "The most recent geological researches seem to point to the possibility of ice periods being recurrent phenomena. We cannot therefore by any means be sure that the scouring marks scratched on our mountains date from the last ice period."

These cautious remarks seem to have been overlooked by many later geologists.

Origin of Mountain-top Detritus

The basis for the assumption that glacial striae and erratics cannot survive a glacial age in northern and arctic countries is the belief that frost splitting is a vigorous process in high mountains and arctic countries today. This belief is mainly based upon observations concerning boulder fields.

Boulder fields (German "Felsenmeere") are extensive masses of boulders found in mountainous and northern localities. They may be the result of outwash of finer materials from tills, they may have been deposited as boulder streams along drainage channels, or the rocks may have fallen down from a steep hillside. There is, however, a type of boulder fields in which the materials *in situ* have been weathered from the underlying rocks. Such deposits are commonly found on the summits of mountains with a sufficiently large summit plateau to permit loose materials to remain in place. The materials are often moved slightly or re-sorted by solifluction and formation of polygons, but this does not obscure their autochtonous character. Almost all mountain-top detritus of the British Isles belong to this class. The term boulder field here refers to all extensive masses of boulders; the term mountain-top detritus is used for the autochtonous class of boulder fields. This is in accordance with the British usage of the term (Tansley, 1949, p. 707). On mountains with a mountain-top detritus, firm rocks are mainly found in the escarpments or as castlelike outcrops near the summits.

Many geologists assume that the summits with mountain-top detritus were covered by ice during the last glacial age. After they became ice free, a vigorous frost splitting took place, owing to frequent fluctuations of temperature across 0°C, and the mountain-top detritus was thus formed.

The argument appears to be circular. The mountain-top detritus is explained as a result of frost splitting, and the existence of the vigorous frost splitting is assumed to explain the origin of the mountain-top detritus. It is questionable whether the available meteorological data justify the assumption that shifts across 0°C are more common in high-alpine and arctic climates than elsewhere.

From thermograms of meteorological stations the annual number of shifts from above to below freezing point can be counted. I have counted the values for 5 successive years for Gaustatoppen (altitude 1828 m) in South Norway, the summit of which carries a boulder field. For comparison I have chosen Rena (altitude 225 m) in a southeast Norwegian valley where ice-polished surfaces abound. The results were

	Gaustatoppen	Rena
1940	69	93
1941	61	86
1942	78	88
1943	91	85
1944	65	95
Average	73	90

The difference between the averages is statistically significant. Shifts of air temperature across 0°C are thus less common on the summit than in the valley.

The number of days per year with shifts across 0°C (Frostwechseltage, frost-shift days) is considered a reasonable measure of the frequency of frost shifts. The frequency of frost-shift days has been extensively studied by Troll (1943) and others. In northern climates, Troll found no relation between the severity of the climate and the number of frost-shift days. The figure is for instance higher for Berlin (67 days per year) than for Green Harbour, Spitsbergen (59 days per year). In Austria, Lauscher (1946) found a maximum frequency

at 1400 m altitude—*i.e.*, well below the timber line.

In temperate climates frost shifts occur mainly in spring and autumn. A maximum number of frost-shift days is expected in climates with a small yearly range of temperature and a mean around 0°C. Such conditions can be found in tropical and subtropical mountains. In the South Peruvian Andes at the El Misti station, Troll found 337 frost-shift days per year. He carefully observed the effect on vegetation and soil formation and found that the vigorous frost at night formed ice needles which affected only the uppermost layer of the soil. The resultant frost shattering formed small pebbles, a peculiar form of solifluction, and small polygons 10–20 cm wide, a picture entirely different from that in northern boulder fields (Troll, 1944, p. 600). A similar frequency of frost shifts, especially at soil surface, has also been observed in the subantarctic islands. In both the subantarctic islands and the subtropical mountains, a characteristic growth form of plants comprising different species and families are observed, called hard-cushion plants ("Hartpolsterpflanzen" in German, "vegetable sheep" of New Zealand). Troll (1947) believes that this particular growth form should be interpreted as an adaptation to the frequent frost shifts at soil level. It is absent in the northern boulder fields.

Hitherto only shifts in air temperature have been considered; the temperature fluctuations in the soil are of course of particular importance to frost splitting. Unfortunately very few stations have soil thermographs, and it has not been possible to count frost shifts in high-alpine and arctic areas. Some observations on the temperature of the rock surfaces have been made in the high Alps by Dirmhirn (1952), who observed daily fluctuations up to 32°C. The amplitude was, however, much reduced if clouds were present, under the influence of wind, and if the rocks had a vegetation cover. The frost shattering due to temperature fluctuations would affect small stones more than large boulders. The resultant disintegration would, presumably, lead to a picture more like that described by Troll from the Peruvian Andes than that observed in the northern boulder fields. It should also be pointed out that a maximum daily amplitude of 32°C is not large when compared with similar observations from less extreme climates.

Frost shifts occur mainly in spring and autumn when the yearly curve crosses the freezing point, the frequency depending upon the angle of crossing and the daily amplitudes. The average soil-surface temperature (except for localities with a snow cover) follows the average air temperature, while in alpine localities it may be somewhat higher (Geiger, 1953). The daily amplitudes are higher than in the air because of insolation and radiation especially on clear days. This effect becomes more pronounced the more the climate is influenced by topography (Geiger, 1950). The average daily amplitudes should therefore be higher in the valleys than on the summits where the wind destroys the pattern of the local climate. The daily amplitudes at the soil surface also depend upon the inclination of the sun—*i.e.*, the higher the sun the greater the insolation. Consequently, smaller daily amplitudes are to be expected in high latitudes. This is substantiated by Sørensen's thermograph records (Sørensen, 1945; *see also* Geiger, 1950).

It has been emphasized (Høgbom, 1914, p. 267–268; Holtedahl, 1953, p. 860) that severity of winter frosts are important in the formation of boulder fields by frost splitting. The observations of Høgbom are mainly confined to Spitsbergen and the mountains of North Sweden, but typical boulder fields occur also in areas with no particularly strong winter frost. Winter frost is not defined more precisely. As a first approximation we may take the mean temperature of the coldest month of the year. Assuming that temperature decrease with altitude is 0.6°C/100 m (a figure commonly employed but probably too high for winter conditions) we can from published meteorological data (Birkeland, 1936; Ångstrøm, 1938; Averages of Temperatures for Great Britain and Northern Ireland, 1936) calculate the mean temperature of the coldest month on the summits with mountain-top detritus. A series of observations on occurrence of typical bouldery mountain-top detritus in oceanic regions with the corresponding mean temperatures of the coldest month is given below; the observation from Moskenesøy is

taken from Vogt (1913, p. 37); the rest are the writer's observations.

Locality	Altitude m	Mean temperature of the coldest month °C
Glyder Fach, Snowdonia, Wales	1000	−0.5
Clisham, Outer Hebrides, Scotland	800	+0.2
Ben Nevis, Scotland	1350	−4.1
Vetten, Bremangerland, West Norway	450	−1.2
Kjærringa, Stadt, West Norway	500	−2.7
West end of Stemshesten, Nordmøre, West Norway	300	−1.9
Moskenesøy, Lofoten, North Norway	600	−4.3

Thus a typical mountain-top detritus occurs in areas with no particularly severe winter frost.

According to Høgbom (1914, p. 280) the lower limit of boulder fields in the Dovre Mountains is at an altitude of 1600 m, corresponding to a mean temperature of −18°C of the coldest month. In the Jotunheimen Mountains the lowest boulder fields are at an altitude of 1700 m (writer's observation) corresponding to a mean temperature of −20°C of the coldest month. Near Røros approximately 100 km east of Dovre (writer's observation) there is no mountain-top detritus on the summits about 1400 m with a corresponding winter temperature of −19°C. In northernmost Sweden the lowest boulder fields (Høgbom, 1914, p. 280) are at 1200 m corresponding to a mean temperature of about −16°C in the coldest month. In North America there are areas with severe winter frosts (Catskill and Adirondack Mountains, parts of Quebec in Canada) but with no mountain-top detritus. These data indicate no satisfactory correlation between severity of winter frost and occurrence of mountain-top detritus.

Goldthwait (1940) pointed out the stability of the boulder fields of Mt. Washington, New Hampshire, as indicated by a comparison of 50-year-old photographs with the present-day picture. An engraving from 1781 (North, Campbell, and Scott, 1949, Pl. V) shows a peculiar rock configuration of the stones of the mountain-top detritus at Glyder Fach, Snowdonia, Wales. The writer visited the locality in 1952, and hardly a stone had moved. On the whole the stones of the mountain-top detritus appear to be very stable. They are commonly covered with large lichens of the family Umbilicariaceae. According to Frey (1947) these grow very slowly. In high-alpine localities in the Alps they require several hundred years to attain full growth. In the valleys of Austria the radial growth of crustaceous lichens is so slow that the size of the specimens can be used for dating stages of retreat of the glaciers since 1850 (Beschel, 1950). In North East Greenland the lichens have not covered the rock faces left bare when the ice receded from the maximum glacial readvance about 1740 (Ahlmann, 1941). Lichens of the family Umbilicariaceae are absent where solifluction is in evidence; where they flourish the stones cannot have been turned during the period required for growth.

Thus, observation does not confirm that frost splitting is rapid in areas with mountain-top detritus, and meteorological data do not support the climatological assumptions underlying the hypothesis. New observations on the activity of frost in the mountain-top detritus is needed with more precise observations of the meteorological conditions and a better understanding of how meteorological conditions influence rock disintegration. It may be necessary to consider other ways of explaining the origin of mountain-top detritus.

An important factor in weathering is of course time. Summits with mountain-top detritus may have stood up through the ice, which covered the lowlands and filled the valleys, and may thus have been exposed to the atmosphere much longer than the lowlands and the valleys.

Study of mountain-top detritus on the very summits of mountains, both in West Norway (Dahl, 1948, and unpublished observations) and in Scotland (unpublished observations) indicate that the altitude of the lowest mountains carrying a mountain-top detritus drops in a regular manner toward the ocean. On the coast mountain-top detritus occurs in localities with very little winter frost. In areas where

mountain-top detritus is at low levels, huge cliffs are also formed by the action of the waves. In these areas deeply weathered gneisses seem to grade into the boulder fields. Weathering of the gneisses in the island of Runde, West Norway (Dahl, 1954), as well as in the Hebrides (unpublished data) has been accompanied by formation of appreciable quantities of several clay minerals—*e.g.*, montmorine. These features recall the unglaciated areas of Devon and Cornwall and suggest that mountain-top detritus is the result of a very long weathering cycle in unglaciated areas. These observations seem to be correlative with those of Linton (1948) who followed the preglacial weathering forms of South-West England (the tors) into the Scottish mountains, where extensive masses of mountain-top detritus occurs.

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Short Note

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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MECHANICAL AID FOR PLOTTING AND COUNTING OUT POLE DIAGRAMS

ROBERT W. DUSCHATKO

The writer was recently confronted by the formidable task of plotting, counting out, and contouring more than 10,000 joint readings. To expedite these routine operations, a simple device was constructed which soon became in such widespread demand among other members of the department that it is now a standard piece of equipment. With the increasing application of quasi-statistical methods to the orientation of planar or linear structures, many geologists, in diverse branches of the field, will find occasion to prepare and analyze Schmidt ("equal-area")-net point diagrams. Roughly 75 per cent of the time involved in handling the data by conventional methods can be saved by the use of a mechanical guide such as has been suggested by Biemesderfer (1949).

The arrangement that the writer found to be most satisfactory consists of three elements: a base, a rotary plotting arm, and a counting out template (Fig. 1). The base, a 12-inch fiberboard square with a fixed pivot at the center, is surfaced with a plastic covered dial graduated radially into 2-degree intervals. For convenience, only the two left-hand quadrants are calibrated, so that diametrically opposed bearings are recorded at the same mark. The two standard types of Brunton compass nomenclature are employed on separate scales, but the directions actually indicated are in *natural sequence* with "north-south" at the left and "east-west" at the top and bottom. Thus, for example, the midpoint of the upper left quadrant is marked 45°, 225°, and N. 45° E., S. 45° W. on the respective scales.

The plotting arm is a plexiglass strip that rotates on the base pin. A narrow medial slot, just wide enough to admit a pencil point, extends lengthwise 10 cm from both sides of the center and is divided into 2-degree intervals corresponding to Schmidt-net dip angles. Enumeration is from 0° at the center to 90° at the margin.

For plotting, a circular sheet of paper is tacked to the base with gummed tape, and the rotary arm is pressed onto the pivot and held in place with a thumb screw. A 10-cm marginal circle is penciled with the aid of a hole provided in the arm, and quadrant boundaries are labeled N., E., S., W., sequentially clockwise, *north at the top*. With this arrangement, tabulated dip and strike measurements of *planes* are plotted directly as upper hemisphere *poles* merely by setting the medial line of the plotting arm at the proper strike reading on the base scale and then printing a dot beside the correct dip angle on the arm. Confusion in regard to direction of dip is virtually eliminated by the coincidence of the direction recorded in the field with natural directions denoted on the paper. By continuously manipulating the dip indicator with the left hand and marking with the right, a facility is soon developed whereby the operator can record points almost as rapidly as the figures can be read from a notebook.

Completed point diagrams are counted out by covering them with a sheet of tracing paper and substituting a plastic template for the plotting arm. The counter is adapted from a proposal of Strand (1944), in which the orthodox 1 per cent counting circles are replaced by the projections on a Schmidt net of spherical circles covering 1 per cent of the surface of the parent hemisphere. The resulting pseudo-elliptical figures, quite elongated near the

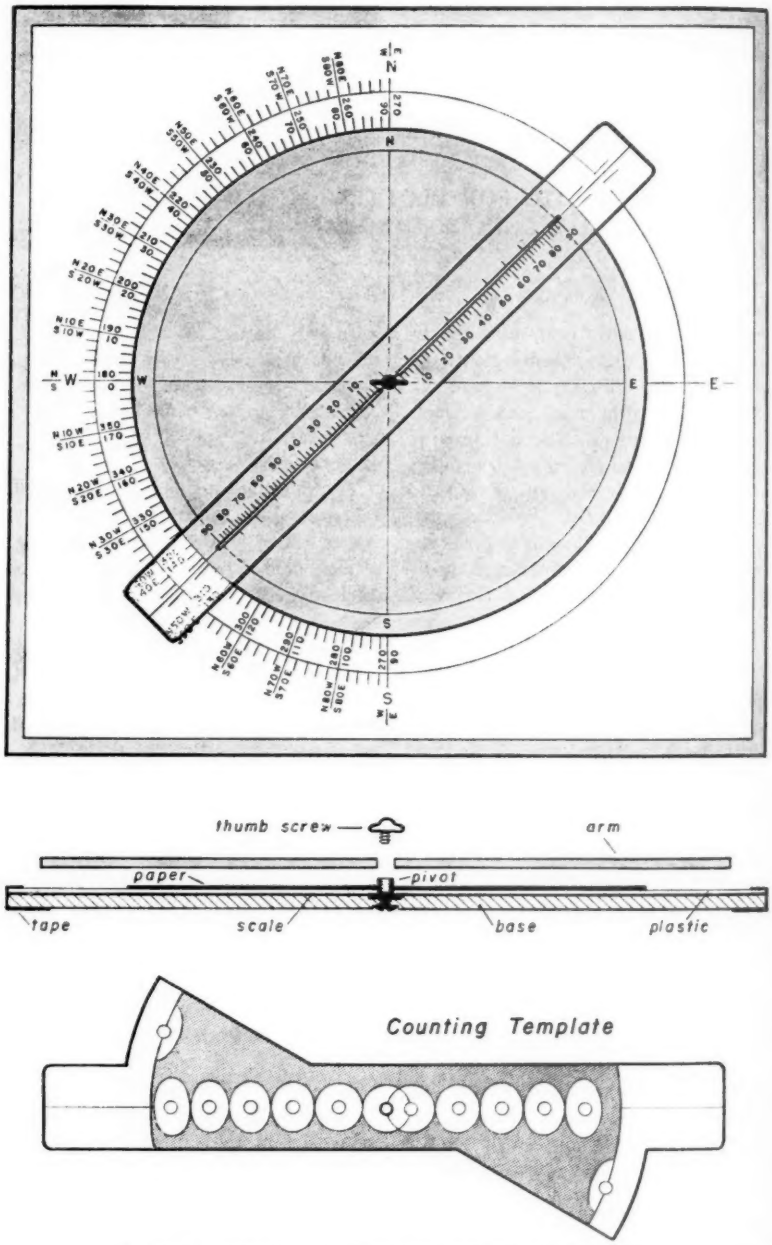

FIGURE 1.—MECHANICAL GUIDE WITH PLOTTING ARM IN PLACE

Upper hemisphere poles are plotted directly. If lower hemisphere poles are desired, "N" and "S", "E" and "W" are respectively interchanged on the paper after completion of each point diagram.

argin of the net, are masked off and ar-nged edge to edge along the diameter of e template. "Ellipses" on half the arm re offset by one radius so that they over-p those along the opposite side, with an ad-tional pair of half counters covering periph-al parts of the diagram. Point densities are arked at the center of each figure as the mplate is progressively rotated at any de-red interval (*e.g.* 5°) through one complete revolution. The final array of numbers is then contoured according to conventional methods.

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APPLICATION OF FLUORESCENT X-RAY SPECTROSCOPY IN GEOCHEMISTRY

Isidore Adler and J. M. Axelrod
U. S. Geological Survey, Geochemistry and Petrology Branch, Washington 25, D. C.

A four-channel x-ray spectrograph and an associated electronic system for measurement have been designed and built in the U. S. Geological Survey and have proved to be a powerful tool in the collection of analytical data on rock, mineral, and soil samples. This device makes possible the determination of up to four elements simultaneously. A curved crystal spectrograph has also been built and is being used for the study of small samples, single crystals, and x-ray diffraction spindles.

Rapid analytical methods have been developed for determining uranium, niobium, tantalum, rubidium, cesium, and selenium in rock samples. Internal standardization has made it possible to deal with widely varying base materials. A quantitative analysis for elements such as thorium can be performed within an hour. Application to geochemical prospecting problems indicates results can be obtained in 2–3 minutes per sample. This has been demonstrated by the determination of lead and zinc in soil samples with a lower limit for zinc of 50 parts per million and lead 75 to 100 parts per million.

PLEISTOCENE BEDS NEAR THE EDGE OF THE CONTINENTAL SHELF, SOUTHEASTERN LOUISIANA

W. H. Akers and A. J. J. Holck
New Orleans, La.; Jackson, Miss.

Pleistocene cores from a well off the lower delta of the Mississippi River (South Pass Block 41) reveal marine sedimentary cycles, which are related, as seen by electrical logs, to previously described updip alluvial deposits. Pleistocene depositional environments may be inferred by analogy with constituents of Recent sediments, particularly Foraminifera. The following regressive and transgressive phases may correspond with glacial and interglacial stages.

A transgressive interval between 3100 and 3600 feet consists of gray shales with abundant Foraminifera of essentially modern species which suggest water depths greater than 600 feet and an Aftonian age. Planktonics are less frequent in sands and shales between 2400 and 3100 feet, and benthonic species indicate an upper neritic origin shoaler than 200 feet. These regressive beds may belong to the Kansan. Foraminiferal gray shales between 2100 and 2400 feet suggest water depths of 600 feet or more and a Yarmouth age. Sands and gray clays of possible Illinoian age between 1500 and 2100 feet contain near-shore elements. Several depositional cycles of lesser magnitude are apparent above 1500 feet in Sangamon and Wisconsin sediments.

Pleistocene deposition appears to have been uninterrupted, and all sediments were laid down in marine or brackish waters. The predominantly sandy section below 3600 feet does not present a means of recognizing the base of the Nebraskan, but it may be logically assumed on the basis of thickness of overlying intervals to be near 4200 feet.

BROAD ASPECTS OF THE APPLICATION OF GEOLOGY TO ENGINEERING PROJECTS IN THE MISSISSIPPI ALLUVIAL VALLEY

Harold V. Andersen
School of Geology, Louisiana State University, Baton Rouge, La.

The stability of the sediment either as a foundation material or to withstand stream erosion is the principal concern of the geological engineer working in the Mississippi River Valley. In the Gulf of Mexico and on the highlands adjacent to the alluvial valley of the Mississippi River where the sedi-

ments are principally sands, silts, and massive clays, most materials are competent, and stream erosion is negligible. In the alluvial valleys, however, where the sediment ranges from gravel to organic muck, foundation materials may be unsuitable, and stream erosion may be difficult to control. This is the sedimentary province of the Mississippi River Valley with multifarious geological engineering problems.

The principal physiographic elements found in an alluvial valley are: backswamps, levees, abandoned stream channels, and occasionally terrace remnants isolated from the adjacent highlands. These physiographic elements are, in general, characterized by certain sized clastics, stream deposited and subject to reworking by the stream occupying the alluvial valley. The backswamps consist of clays and silts or, occasionally, organic mucks. The levees and terraces are principally silt although sand and gravel are present in some of the terraces. The abandoned channels contain sands, silts, and clay; in many places the clay is in the form of "plugs" which may eventually control the meander belt of the stream. These physiographic elements of the alluvial valley grade laterally into and overlap each other to form complex sedimentary sequences which the engineering geologist must evaluate.

RELATIONSHIPS OF CALCIUM CARBONATE TO LITHOLOGY AND VANADIUM-URANIUM DEPOSITS IN THE SALT WASH SANDSTONE MEMBER OF THE MORRISON FORMATION*

N. L. Archbold
Box 360, U. S. Geological Survey, Grand Junction, Colo.

A study was made to determine possible relationships between $CaCO_3$ content and lithology or between $CaCO_3$ and vanadium-uranium deposits in the Salt Wash sandstone member of the Morrison formation. The $CaCO_3$ content was determined for more than 600 samples from the Salt Wash sandstone member. In addition, 140 chemical assays of mineralized rock were obtained for study.

The studies indicate that altered gray-green mudstone contains less $CaCO_3$ than unaltered red-brown mudstone, and that sandstone contains more $CaCO_3$ adjacent to contacts with mudstone. No difference was indicated between $CaCO_3$ concentrations in altered light-gray sandstone and unaltered light-red sandstone.

The concentration of $CaCO_3$ and the grade of mineralized rock do not appear related. The $CaCO_3$ concentrations do, however, seem to parallel ore whether in bedded or roll form. Calcium carbonate is probably redistributed during mineralization.

VARIATIONS OF SULFUR ISOTOPES IN SULFIDE MINERALS

Wayne U. Ault
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

A reconnaissance study was made of the sulfur isotopic ratios in some 80 samples of hydrothermal, magmatic, and pegmatitic sulfides. The S^{32}/S^{34} ratio of these sulfides ranged from 21.55 to 23.0 relative to meteoritic sulfide as 22.21.

The sulfur-isotope ratios within a deposit appear to be independent of the mineral species (pyrite, marcasite, calcopyrite, sphalerite, galena, pyrrhotite, bornite, realgar, arsenopyrite, chalcocite), crystal habit, and possibly temperature and rate of deposition to at least a few tenths of a per cent. The S^{32}/S^{34} ratio does appear to be related to the source of the sulfur. Sulfide in pegmatite that was derived from enclosing schist and gneiss rock shows high S^{32}/S^{34} ratios consistent with an ultimate origin from sedimentary sulfide. Sulfide associated with mafic or ultramafic rocks of deep-seated origin shows a S^{32}/S^{34} ratio near 22.2—*i.e.*, that of meteoritic sulfide. The Ivigtut galena shows a S^{32}/S^{34} ratio expected from a sulfate environment, and the lead isotope abundances are consistent

* Publication authorized by the Director, U. S. Geological Survey and the U. S. Atomic Energy Commission

with this, indicating an environment low in U/Pb. A comparison of the lead and sulfur isotope abundances in Mississippi Valley type leads indicates that the variation in the lead-isotope abundances is not due to isotopic fractionation during transportation or deposition.

CHANGES TO THE ABSORPTION SPECTRA OF KAOLINITE AND MONTMORILLONITE DURING DEHYDRATION

Allan Auskern and Rex W. Grimshaw
Pennsylvania State University, University Park, Pa.

The infrared absorption spectra of a series of carefully heated kaolinite and montmorillonite samples were obtained. The absorption curves give the following information: the order of disappearance of absorption bands, changes in the position of absorption bands, and the appearance of new absorption bands. Some of the spectral changes can be related to structural changes taking place during dehydration. Also, the information obtained permits some absorption bands to be assigned to the vibrations of particular structural units.

In kaolinite, seven absorption bands between 9 and 15 microns are no longer apparent after dehydration. The strong band at 9.66 microns in the unheated clay shifts to 9.4 microns with the elimination of the surface hydroxyl units. The spectral changes for montmorillonite during dehydration parallel strongly those of kaolinite and are quite unlike those of other 2:1 layer minerals—namely, pyrophyllite and illite.

ALTITUDE OF THE SIERRA NEVADA AND WESTERN NEVADA DURING MIO-PLIOCENE TIME

Daniel I. Axelrod
Dept. of Geology, University of California, Los Angeles, Calif.

About twenty Mio-Pliocene floras distributed from sea level in west-central California, across the Sierra Nevada, and into western Nevada occur either (1) at or near the base of the upper Tertiary Sierran andesite (Mehrten formation, Kate Peak andesite) and its equivalents to the east and west, or (2) in the underlying Valley Springs formation and its close correlatives in western Nevada and coastal California.

Since the floras are related to living communities whose topographic and climatic relations can be measured, they provide a basis for estimating the altitude of the Sierra Nevada and of west-central Nevada during Mio-Pliocene time. Local, provincial, and regional comparisons indicate there were only moderate east-west differences across this transect where environmental diversity is marked today.

Paleogeographic inferences include: *Topographic*—Just prior to late Tertiary vulcanism the Sierra Nevada was the site of a broad ridge whose summit lay near 3000 feet. The lowlands of west-central Nevada had an average elevation near 2000 feet. *Climatic*—Building up the Sierran ridge over 6000 feet in post- Mio-Pliocene time (1) lowered rainfall over the lowlands to leeward sufficient to account for the present desert, and (2) reduced temperatures along its summit so that an arctic-alpine zone came into existence. *Biologic*—Plants and animals gradually invaded these, developing *new zones* during late Cenozoic time from contiguous milder environments, areas in which the present-day types of the extreme environments find most of their relatives.

REGIONAL GRAVITY INVESTIGATIONS IN MICHIGAN'S UPPER PENINSULA

Lloyal O. Bacon
Michigan College of Mining and Technology, Houghton, Mich.

A regional gravity study of the Upper Pensinsula of Michigan has been carried out over a period of 4 years. More than 4000 gravity stations have been occupied with station density ranging from

less than one per square mile in some of the mining districts to one per township in the eastern portion of the peninsula.

Large gravity anomalies associated with the Keweenawan lava flows make it possible to predict the contact with Huronian sediments beneath thick glacial drift.

A broad gravity anomaly in the eastern half of the Upper Peninsula is believed to be a result of a basement ridge dividing the Lake Superior and Lake Michigan basins.

There is an excellent correlation between gravity maxima and the thick Huronian sedimentary basins which contain iron formations. Many local anomalies may have significance as an exploration guide in iron-ore prospecting.

PRECAMBRIAN PLUTONISM AT MINERAL RIDGE, ESMERALDA COUNTY, NEVADA

Paul A. Bailly and Robert R. Compton
Bear Creek Mining Co., Minneapolis, Minn.; Stanford University, Stanford, Calif.

Mineral Ridge, an eastern branch of the Silver Peak Mountains, provides an unusually well-exposed record of Precambrian plutonism. The ridge is a northwest-southeast trending anticline whose core is essentially an elongate dome of "Archeozoic" granite, overlain successively by thickly layered pegmatite, "Archeozoic" metasedimentary rocks, and "Proterozoic" metasedimentary rocks, in a series of giant, crudely conformable shells.

The first period of Precambrian plutonism began with the metamorphism of a sequence of sedimentary rocks to garnet-mica schist, marble, and calc-silicate rocks of epidote amphibolite facies. Much granite pegmatite was injected into the metamorphic rocks, forming bodies that range from thin *lit-par-lit* layers to large conformable lenses. Post-intrusional folding produced widespread cataclasis and boundinage, and in many places mineral assemblages were reduced to greenschist facies. Finally, the foliate complex was cut by granite that apparently arose from the large mass that forms the core of Mineral Ridge.

After deep erosion, "Proterozoic" dolomite and minor epiclastic sediments were deposited over the "Archeozoic" complex, and these were subsequently metamorphosed to dolomite marble, feldspathic quartzite, and schists of greenschist facies. Locally, this sequence was folded into the "Archeozoic" rocks, but, generally, it is conformable to the Mineral Ridge anticline. After folding, podlike bodies of granite pegmatite intruded the rocks. Lepidolite from one of them is 700 million years old, as determined by Ahrens' Rb—Sr method. Erosion marked the latest Precambrian, for unmetamorphosed fossiliferous Lower Cambrian strata overlie the Precambrian rocks.

STABILITY OF MAGNETITE AND HEMATITE IN A HYDROTHERMAL ENVIRONMENT FROM THERMODYNAMIC CALCULATIONS

Donald R. Baker
Department of Geology, Northwestern University, Evanston, Ill.

The free-energy increase and hence the equilibrium constants and equilibrium partial pressures of O_2 [$p(O_2)$] for the magnetite-hematite reaction ($2Fe_3O_4 + \frac{1}{2}O_2 = 3Fe_2O_3$) for temperatures of 600°-1600°K and pressures of 1–7000 atm. have been determined. Univariant equilibrium isobars for the pressures 1, 10, 100, 1000, 2000, 5000, and 7000 atms. were plotted in a diagram with reciprocal temperature and $p(O_2)$ (10^{-34} to 1 atm.) as co-ordinates. The univariant isobars separate the stability fields of magnetite and hematite and give the $p(O_2)$ for a system in which these minerals exist at equilibrium.

The equilibrium constants for the water reaction ($2H_2 + O_2 = 2H_2O$) which are known for temperatures of 700°–1200°K at 1 atm. pressure were extrapolated to water pressures up to 5000 atms. by standard thermodynamic calculations. Using these constants the dissociation $p(O_2)$ and $p(H_2)$ for

the water reaction were calculated, and univariant isobars were plotted for the water pressures 1, 10, 100, 1000, 2000, and 5000 atms. on a diagram in which reciprocal temperature and $p(O_2)$ (10^{-12} to 10^{-6} atm.) or $p(H_2)$ (10^{-11} to 10^{-5} atm.) are co-ordinates.

Utilizing the two sets of univariant isobars and assuming a mineral paragenesis of magnetite and hematite formed at equilibrium with water vapor at a given temperature and pressure, the equilibria $p(O_2)$ and $p(H_2)$ for the system are obtained from the isobars. Further, the isobars give a maximum value of $p(O_2)$ for petrologic systems in which magnetite occurs to the exclusion of hematite. In addition the isobars show that in cooling from a magnetite-hematite-water equilibrium there is a continual production of "excess" O_2 so that magnetite is continually oxidized to hematite; hence, some martite is a retrograde mineral.

DRAINAGE DEVELOPMENT, SOUTHERN SACRAMENTO MOUNTAINS, NEW MEXICO

Robert L. Bates
Dept. of Geology, Ohio State University, Columbus, Ohio

The Sacramento Mountains of south-central New Mexico are an asymmetrical fault block of Paleozoic sedimentary rocks, with a long gentle eastern slope draining to the Pecos River and a steep western escarpment fronting on the Tularosa Basin. A zone of Late Tertiary normal faulting bounds the range on the west. In the southern part of the range, a second normal-fault zone appears east of the main one, and there the mountains rise in two escarpments. The asymmetrical trough formed by the back slope of the lower fault block and the steep escarpment of the higher one opens to the southeast and is drained by the Sacramento River and its tributaries (ephemeral streams, as are all those of the range). These conditions have set the stage for the spectacular development of stream piracy. Steep streams flowing into Tularosa Basin are capturing drainage from the western limb of the Sacramento River basin and now threaten the main channel itself. The eastern tributaries of the Sacramento River, in turn, are capturing and reversing the headwaters of eastward-flowing Pecos River drainage. Examination of air photos, Forest Service contour maps, and the area itself reveals a multitude of barbed tributaries, elbows of capture, beheaded streams, and abrupt changes in gradient. These are described as illustrating the close control exercised by geologic structure in the early evolution of a drainage pattern.

SOME ASPECTS OF THE GEOCHEMISTRY OF GALLIUM*

C. K. Bell
Geological Survey of Canada, Ottawa, Canada

Quantitative spectrochemical investigations involving a grating spectrograph, indium as internal standard, and Ga 4172:In 4101 as analyses pair contribute new abundance data and indicate gallium's ubiquity, narrow scatter, and close association with aluminum in silicate minerals and rocks. Analytical detection limit is 0.0001%. Reproducibility expressed as standard deviation is 11%. Rock-forming orthoclase averages 0.0014% gallium, plagioclase 0.0019%, biotite 0.0019%, and muscovite 0.0029%. Pyroxenes average 0.0005%, and amphiboles 0.001%. Gallium concentrates in end-phase minerals during differentiation, amazonite averaging 0.0037%, lepidolite 0.0069%, and spodumene 0.0033%. Results indicate preferential enrichment in platy minerals containing octahedrally coordinated Al^{3+}. Gallium is not detectable in dunites and serpentinites, pyroxenites contain less than 0.0003%, gabbros 0.0016%, and granites 0.0017%. Shales average 0.0019%. Metamorphosed equivalents contain comparable percentages. The lithosphere averages 0.0015%. The Ga. 1000/Al ratio increases during differentiation from 0.11 in dunites through 0.17 in gabbros to 0.22 in granites and

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0.4 in late pegmatites. Igneous rocks average 0.19, but this increases to 0.23 in sediments. Abnormally high ratios in some aluminum-deficient ferromagnesian minerals (hedenbergite 0.816, anthophyllite 0.675) suggest that Ga^{3+} enters the Fe^{2+} and Mg^{2+} structural positions. Low ratios (cryolite 0.007) are partly explained by Al^{3+} being lithophillic only, while Ga^{3+} with the larger radius and ionization potential is also chalcophillic. Because of its varying valency gallium can enter covalent bonding, substitute for sulfur in sulfides, and leave all associated aluminum minerals impoverished in gallium.

RELATIONSHIP OF COMPOSITION TO THERMAL STABILITY IN THE HUEBNERITE-FERBERITE SERIES

Joseph Berman and William J. Campbell
Eastern Experiment Station, U. S. Bureau of Mines, College Park, Md.

An investigation was undertaken to determine the feasibility of obtaining the wolframite content of scheelite ores by x-ray diffractometry.

A survey of the stronger wolframite diffraction lines indicated that the 010 reflection seemed to be a logical choice as it was free from interferring lines of scheelite and the common impurities usually associated with scheelite. However, quantitative studies showed variation in the intensity of this 010 reflection with samples from various sources and with their iron-manganese ratio.

The 010 reflection arises from the cleavage plane that results in preferred orientation. As it was known that this orientation could be reduced by heating, a number of samples analyzed by fluorescent x-ray spectrography were heated at 950°C in helium and in air.

The samples heated in helium have relatively equal intensities of their 010 reflections regardless of source or composition. The samples heated in air were unstable except for the high manganese members of the series, those having a manganese/iron ratio greater than 2. The higher iron members transformed to a new iron-rich phase plus a wolframite structure of greater manganese content. The manganese/iron ratio of the series can be determined by measuring the increased β angle and comparing to a previously calculated calibration curve. The β angles for the monoclinic members of the series were determined by comparing the experimentally measured (111-$\bar{1}$11) with calculated values. This β angle is approximately a linear function of the manganese/iron ratio; it ranges from 91°07′ for the 100% manganese member to 90° for the 100% iron member of the series.

LATE QUATERNARY PHYSIOGRAPHIC HISTORY OF SOUTHERN LOUISIANA

Hugh A. Bernard
Shell Development Company, 3737 Bellaire Blvd, Houston 25, Texas

The last major cyclical fluctuation in sea level, correlated with the advance and retreat of Late Wisconsin ice masses and with postglacial time, constitutes the Late Quaternary cycle. The events of this cycle in Louisiana are well known and appear to be similar to those of the previous four cycles.

During the early phase of the Late Quarternary cycle a lowering of sea level caused rivers entering the Gulf of Mexico to become deeply entrenched. Valley systems were eroded, and the slope of their floors indicates that sea level was lowered approximately 450 feet. At the time of maximum entrenchment, streams were depositing sediments beyond the edge of the Continental Shelf.

Entrenched valleys were alluviated during the middle phase of the cycle as sea level rose in response to waning glaciation. A progressive reduction in stream-carrying capacity brought about by rising base level is reflected by the alluvial fill; basal sands and gravels grade into overlying sands, silts, and clays. When the sea reached its present level at the beginning of the late phase, stream valleys were drowned, and estuaries had deeply embayed the Louisiana shore.

Development of the Mississippi deltaic plain and contemporaneous growth of the chenier plain in southwest Louisiana have occurred during the late phase. Well-defined distributary systems, each marking the position of a delta, record changes in the river course during growth of the deltaic plain, and prominent abandoned beach ridges mark stages in the development of the chenier plain.

STRATIGRAPHIC TERMINOLOGY OF THE PALEOZOIC ROCKS IN THE SOUTHERN GREAT SALT LAKE BASIN

Harold J. Bissell and J. Keith Rigby
Department of Geology, Brigham Young University, Provo, Utah

Relatively complete sequences of Cambrian through Permian rocks are exposed in the mountain ranges along the Nevada-Utah line and eastward to the Wasatch Range.

Widely recognized lithic units eliminate the need of erecting new stratigraphic names from district to district, range to range. Detailed measured sections and geologic mapping demonstrate the areal extent and inter-relationship of the northern Utah, Great Basin, and central Utah facies. The Stansbury Mountains, south of Great Salt Lake, constitute the key area for interpretation. Stratigraphic terminology proposed for the Tinctic district can be traced here from the southeast; lower and middle Paleozoic nomenclature can also be applied, particularly in the southwestern Stansbury area. Ordovician and Silurian formations of northern Utah can be recognized along the west and northern parts of the range. Stratigraphic relations of formations of the Devonian system of both the Tinctic and Gold Hill districts are exposed. Stratigraphic terminology of the Mississippian and Pennsylvanian rocks of the Tinctic and Oquirrh mountains can be applied over most of the area. Permian strata of the Wasatch Mountains grade westward into rocks where Grand Canyon terminology, in part at least, can be applied.

STUDY OF THE MARKED POSITIVE GRAVITY ANOMALY IN THE NORTHERN MID-CONTINENT REGION OF THE UNITED STATES

W. A. Black
The California Company, New Orleans, La.

This investigation has a two-fold purpose: (1) to delineate the areal extent and amplitude of the anomaly; (2) to interpret the anomaly in terms of geologic factors that will explain it. The anomalous area extends from the northeast corner of Kansas to the northwest corner of Wisconsin and ranges from 29 miles to 110 miles in width. The 1500 gravity stations used in the study express the feature as an elongate north-south positive Bouguer anomaly ridge flanked to the east and west by parallel negative Bouguer troughs. The maximum gravity gradient measured was at Mason City, Iowa, with Bouguer anomaly values ranging from west to east of −143 mgls to +50 mgls to −125 mgls in a distance of 29 miles.

Eleven profiles were analyzed geophysically, and depth computations were based on the anomalous mass approximating infinitely long horizontal cylinders. The calculated depths to the center of mass indicate the geologic conditions causing the anomaly are of crustal proportions in either positive or negative anomaly areas.

The Bouguer anomaly map, the analysis of gravity profiles, and the postulated geological conditions indicate an en echelon "rift" pattern developed in the crust during late Precambrian time and genetically related to the development of the Lake Superior geosyncline of the Proterozoic.

FURTHER STUDY OF THE CLEAVAGE TENDENCIES IN QUARTZ

F. Donald Bloss
University of Tennessee, Knoxville, Tenn.

The 100–200 mesh fragments of crushed crystal, rose, and milky quartz were mounted on slides and examined by petrofabric techniques. The angle between the optic axis and the normal to the surface on which the grain rested was determined for at least 400 fragments of each sample, and the results plotted as histograms. Under the assumption of complete crystallographic independence of fracture surface, a histogram following the sine distribution would be expected. Actually, however,

the observed data for all varieties indicate peaks near the 52° region with lesser peaks near the 90° region.

For quartz crushed at room temperature these peaks were interpreted to be the result of cleavage parallel to the *r* and *z* rhombohedra and of cleavage parallel to the *m* prism or the *x* ($51\bar{6}1$) direction, respectively. The 52° peak was higher for quartz crushed above 573°C than for the quartz crushed at room temperature. Therefore the cleavage of high quartz parallel to the unit pyramid ($10\bar{1}1$) direction is superior to the cleavage along the corresponding direction in low quartz.

Comparison of these histograms with those prepared by Fairbairn and by Ingerson and Tuttle for the crystallographic orientation of deformation lamellae indicate a rather antipathetic relationship. The fracture hypothesis for the formation of deformation lamellae thus appears untenable.

Method of crushing had a slight effect on the results. Quartz crushed in a hammermill rather than by ramrod action in a steel pipe yielded histograms with slightly sharper peaks.

MORPHOLOGIC VARIATION IN ZOARIA OF SOME TREPOSTOMATOUS BRYOZOA

Richard S. Boardman
U. S. Geological Survey, Washington 25, D. C.

The range of morphologic variation in nearly complete branching zoaria of trepostomatous Bryozoa from the Hamilton group (Middle Devonian) in New York State indicates that species have been differentiated on material that could be from a single zoarium. Detailed sectioning of these zoaria discloses that three categories of variation of accepted species characters can be distinguished within a zoarium: (1) variation distributed progressively from older to younger parts of a zoarium and controlled by astogeny (life history of a colony); (2) variation evently distributed and adequately represented in a small fragment of a zoarium; and (3) variation widely and erratically distributed. Astogenetic characters—the number of diaphragms, width of the thick-walled zone, and axial ratio—show profound differences between well-developed colonies and those killed at an early growth stage. A comparable range in astogenetic variation exists at opposite ends of the well-developed colonies.

In the average collection of Bryozoa consisting of discrete fragments of zoaria, astogenetic characters can be evaluated by use of scatter diagrams which permit the construction of regression lines and other statistical tests. Alternatively, growth stages can be arbitrarily defined using one character such as the number of diaphragms as the independent variable and recording corresponding measurements of other astogenetic characters in chart form. The range of variability of these astogenetic characters indicates that some species have been too narrowly defined.

SEISMIC-REFRACTION STUDIES OF GEOLOGIC STRUCTURE IN NORTH CAROLINA AND SOUTH CAROLINA

William E. Bonini
Dept. of Geological Engineering, Princeton University, Princeton, N. J.

Fifty-five seismic-refraction measurements were made along five traverses in North Carolina and South Carolina to determine depth to and lithology of the basement complex beneath the Coastal Plain sediments. Two traverses were carried from the Fall Line to the coast, one was run parallel to the coast midway between the Fall Line and the coast, and the other two were carried coastward to a basement depth of 2000 feet, the limit of the equipment. Seismic-velocity measurements were made at more than 20 sites in the Piedmont area on exposed basement rocks to aid in the correlation between velocities and lithology.

In general two and occasionally three seismic horizons were recognized above basement. Variations in crystalline basement velocities tended to parallel the regional strike of the Piedmont. A new area of Triassic sediments near St. Charles, South Carolina, was found. The Cape Fear axis proved to be

a pronounced basement ridge at the coast which gradually merged into the pre-Cretaceous peneplain surface near the Fall Line.

SAN ANDRES FORMATION IN THE BROKEOFF MOUNTAINS, SOUTHEASTERN NEW MEXICO

Donald W. Boyd
Union College, Schenectady, N. Y.

Correlation of the Permian shelf and basin sections in the western Texas-southeastern New Mexico area has been hindered by insufficient knowledge of the San Andres formation in the critical belt of facies change. Representative deposits of this belt are exposed in the fault blocks of the Brokeoff Mountains.

In this area, the San Andres formation is 600 feet thick and overlies the Victorio Peak member of the Bone Spring formation. The lower part of the San Andres passes into the Cutoff member of the Bone Spring, whereas the upper part is equivalent to much of the Cherry Canyon sandstone tongue. The transition belt between San Andres and Cherry Canyon is characterized by patch reefs; it marks the position of the Delaware Basin margin during deposition of the upper San Andres. The belt is parallel to the trend of the Capitan reef, as exposed in the near-by Guadalupe Mountains, but is approximately 9 miles northwest of the Capitan.

After deposition of the San Andres formation, the basin margin was established farther south. Shelf deposits, largely dolomites, overlie both the San Andres and the Cherry Canyon tongue.

The top of the San Andres formation is placed at a change in character of the carbonate section. In contrast to the San Andres, the lighter-colored overlying beds originated as calcarenite and calcilutite and are relatively unfossiliferous. However, distinctive laminations in many beds are probably the result of sediment binding by algae.

EXPERIMENTAL STUDY OF THE CALCIFEROUS AMPHIBOLES

F. R. Boyd
Geophysical Laboratory, 2801 Upton Street, N. W., Washington 8, D. C.

A hydrothermal investigation of the calciferous amphiboles has been undertaken with the primary purpose of defining their stability limits. Tremolite ($Ca_2Mg_5Si_8O_{22}(OH)_2$), pargasite ($NaCa_2Mg_4AlAl_2Si_6O_{22}(OH)_2$), and a series of amphiboles on the tremolite-tschermakite ($Ca_2Mg_3Al_2Al_2Si_6O_{22}(OH)_2$) join have been synthesized.

Tremolite breaks down according to the reaction: tremolite $\leftrightarrows$ enstatite + diopside + quartz + vapor. The temperature of the breakdown curve at 1000 bars H_2O pressure is 935° C. The optical properties of synthetic tremolite are: $N_x = 1.625$; $N_z = 1.601$; $2V = -73° \pm 1°$; $N_z \wedge C = 16° \pm 2°$.

The stability range of the magnesian hornblende, pargasite, has been determined. The breakdown reaction for pargasite is: pargasite $\leftrightarrows$ aluminous diopside + nepheline + fosterite + anorthite + spinel + vapor. The breakdown curve passes through the points: 820° at 200 bars (H_2O); 928° at 400 bars (H_2O); 990° at 600 bars (H_2O); and 1027° at 800 bars (H_2O). At H_2O pressures greater than 800 bars pargasite does not break down in the solid state but melts incongruently to aluminous diopside + fosterite + spinel + liquid + vapor. The incongruent melting curve passes from the invariant point at 1027° C. and 800 bars (H_2O) through the point 1045° and 1000 bars (H_2O). The optical properties of synthetic pargasite are: $N_x = 1.645$; $N_z = 1.624$; $2V = +74° \pm 4°$; $N_z \wedge C = 21° \pm 2°$.

The relatively high temperatures of these amphibole breakdowns are in accord with the common occurrence of amphiboles as primary phases in igneous rocks and with the persistence of amphiboles to very high grades in metamorphic rocks.

CHANGE IN FOUR GROUPS OF MICROFOSSILS FROM THE EOCENE TO OLIGOCENE OF THE OCEANIC FORMATION OF BARBADOS

M. N. Bramlette
Scripps Institution of Oceanography, La Jolla, Calif.

Most of the Oceanic formation of Barbados is considered Eocene, though the lithologically similar upper part has been classed as Oligocene from studies of the Foraminifera.

The writer's study of the coccolithophorids indicated a distinct change between two samples in a series taken at about 10-foot intervals. This change corresponds to that recognized elsewhere between the Eocene and Oligocene. Independent examination of these samples by specialists on the Foraminifera (by Beckmann), Radiolaria (by Riedel), and diatoms (by Kanaya) indicates a corresponding change in each case.

A considerable change in the water mass seems indicated, and the change in the Radiolaria suggests that more than the surface water was involved. The lithology of the deep-water bottom sediments was little affected, however.

The surprising implication is that some such change in the ocean water was more than local. The change in the three groups of organisms, for which age interpretations were made, corresponded to that between the Eocene and Oligocene elsewhere. No consideration of evolutionary changes is yet possible, but such changes are probably of minor significance as might be expected in the time involved between the two samples, from strata without evidence of considerable discontinuities. Evolutionary changes in all four groups of organisms at the same time would seem strange also, except as influenced by some considerable change, perhaps largely of temperature, of the ocean waters.

ASSOCIATION OF URANIUM WITH A NATURALLY OCCURRING COAL EXTRACT

Irving A. Breger
U. S. Geological Survey, Washington 25, D. C.

Uranium and vanadium are associated with several types of carbonaceous material on the Colorado Plateau. Besides coalified wood and crude oil, there is also a black, lustrous carbonaceous material that usually contains sufficient uranium to classify it as an ore. No cellular structure has been identified in this material, which occurs either as an impregnation in sandstone or as pellets ranging from several millimeters to several centimeters in diameter. In some regions the material—variously called asphaltite, thucholite, or glance pitch in the literature—is in apparent association with crude oil, leading to the suggestion that it is a petroleum residue. Because of its apparent importance in the geochemistry and emplacement of uranium on the Colorado Plateau, investigations of this material have been carried out in some detail.

Ultimate analysis, differential thermal analysis, and infrared absorption analysis all show the carbonaceous material to be similar to a low-rank coal in composition and chemical structure and to be unlike other asphaltites such as gilsonite or wurtzilite. Autoradiographic studies also show that the uranium is nearly homogeneously dispersed in the carbonaceous matter. The evidence obtained to date shows that this so-called asphaltite is not related to crude oil but rather is a coal extract derived from coalified wood in the region and precipitated under the proper physical and chemical conditions. The highly insoluble nature of the coal extract is thought to result from cross-linkage of coal molecules as a result of irradiation by alpha particles.

MAGMATIC DIFFERENTIATION IN THE FRANCISCAN-KNOXVILLE GROUP OF THE CALIFORNIA COAST RANGES

Louis I. Briggs, Jr.
Department of Geology, University of Michigan, Ann Arbor, Mich.

The magmatic history of the eugeosynclinal Franciscan-Knoxville group is expressed in extensive mafic and ultramafic intrusive serpentine, peridotite, gabbro, diorite, and basic lavas. Quartzose differentiates are extremely rare as is typical of the peridotite-serpentinite association in folded belts of the Alpine type.

Petrogenic studies of the rocks from the two recorded occurrences of quartz-bearing gabbro in Diablo Range show that (1) quartz occurs throughout the diorite and gabbro and is concentrated in granophyric dikes and veins; (2) pyroxene (enstatite and clinopyroxene) is extremely iron poor and but slightly differentiated; (3) abundant quartz, amphibole, magnetite, ilmenite, and chlorite probably represent a late endomorphic phase of the quartz gabbro rich in volatiles.

Field relationships suggest a common genesis for the serpentinite, quartz gabbro, and spilitic lavas. Development of the major magmatic intrusive phase in Diablo Range occurred during initial displacement of the large thrust that borders the Franciscan core of the range for approximately 175 miles, suggesting a deep-seated origin for the magma. The low degree of differentiation toward a silica- and iron-rich residium is attributed to extreme basicity of the parent magma and low temperature of intrusion, probably both the result of deep-seated orogenesis.

CLASTIC LIMESTONE DIKES, STE. GENEVIEVE COUNTY, MISSOURI

Kenneth G. Brill, Jr.
Institute of Technology, St. Louis University, St. Louis, Mo.

Fifteen limestone dikes intrude a bed of the St. Louis limestone. Their average width exceeds 1 inch, and the widest is about 2 inches. The greatest vertical dimension exposed is 12 feet. The bearing of the dikes is similar to that of two sets of vertical joints in the wall rock. The wall rock consists of thin-bedded, lithographic limestone interbedded with laminae of calcareous shale. Along the four largest dikes the wall rock is dragged upward about an inch.

The larger dikes consist of granules, oolites, and *Endothyra*. A breccia of fragments which resemble the wall rock occurs in the top of some dikes. Some have a thin lining of calcareous shale between the dike and wall. Similarity of lithology and insoluble residues indicate that the dikes were intruded from the underlying clastic limestone.

During diagenesis the lithographic limestone becamse compact enough to be jointed, while the underlying clastic limestone remained unconsolidated enough to be pressed into the joints. On the other hand the dikes were rigid enough to cause drag on the walls or to stand firm while the wall rock sank downward. The dikes also pushed a breccia of wall-rock fragments upward. The argillaceous linings suggest that water moved laterally into the wall causing plastering of suspended clay along the walls of the dikes.

LAMONT C^{14} STUDIES

W. S. Broecker and J. L. Kulp
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

C^{14} measurements on samples from Atlantic Ocean cores and the Mississippi Delta allow preliminary estimates of the chronologies of surface ocean temperature and sea level. Measurements on cores from widely differing latitudes and longitudes in the Atlantic indicate that the sharp in-

crease in surface-ocean temperature recorded by the Foraminifera in cores throughout the Atlantic occurred simultaneously at 10,700 ± 700 years B.P. Extrapolation of the average deposition rate obtained between 11,000 and 35,000 years B.P., in a core where evidence indicates that no erosion or slumping altered the normal deposition, gives an approximate date of 70,000 years for the beginning of this cold surface ocean water period.

Samples from the Mississippi Delta place the age of the maximum of the most recent sea level lowering (−450 feet) at >35,000 years and indicate a sea level of about −120 feet 10,000 years ago and approximately −200 feet 20,000 years ago.

Measurements on carbonate from water samples taken at various depths in the Atlantic give differences up to 800 years between surface and bottom water. Revised sampling and chemical techniques combined with good internal consistency in the 25 samples measured allow confidence to be placed in the reliability of these measurements. Since the differences are small definite conclusions concerning ocean circulation await more extensive sampling.

REVISION OF STRATIGRAPHY AND STRUCTURAL FEATURES IN THE GRENVILLE SERIES, EDWARDS-BALMAT DISTRICT, NORTHWEST ADIRONDACKS, NEW YORK

J. S. Brown and A. E. J. Engel
St. Joseph Lead Co., Bonne Terre, Mo.; California Institute of Technology, Pasadena, Calif.

New surface and subsurface data suggest major reinterpretations of stratigraphy and structure in this area. Principal metasedimentary units are reduced to (1) marble and (2) migmatitic paragneiss. The paragneiss, about 2500 feet thick, is oldest. Younger marble, about 2000 feet thick, is differentiated into 15 zones, mostly dolomite and silicated dolomites, but one containing much anhydrite, another H_2S and graphite. Potassic migmatite about 400 feet thick and minor dolomitic marble lie stratigraphically above this sequence.

The metasedimentary units are irregularly metamorphosed and contorted into northeast-trending, gently to moderately plunging folds, commonly isoclinal. These merge abruptly into and are blurred and refolded by northwest-plunging cross-folds and associated shears involving stratigraphic displacements of several miles. The northeast-trending folds are accordant elements in a regional system, seemingly induced by major southeast-northwest crustal shortening. Cross-folds and major shears are confined largely to two sinuous, northeast-trending zones bordering large massifs. The zone that includes much of the District is more than 45 miles long, and component cross-folds have a common direction sense. Axes of some seem to intersect axes of northeast-trending folds at high angles. Largest folds of both types have radii of curvature exceeding 1 mile.

The cross-folds and shears can hardly reflect incidental "convergent" or "extrusion" flow as the regional fold system formed. They seem products of a major northeast-trending crustal couple either during or following final growth stages of the northeast-trending regional folds.

PHASE EQUILIBRIA IN THE SYSTEM $CaO—Al_2O_3—SiO_2—H_2O$. II. THE SYSTEM $CaSiO_3—H_2O$ AND THE INFLUENCE OF Sr^{++} IN SOLID SOLUTION

D. Buckner and R. Roy
Dept. of Geophysics and Geochemistry, The Pennsylvania State University, University Park, Pa.

The minerals pseudo-wollastonite, wollastonite, xonotlite, "B", and tobermorite occur in the system. Hydrothermal-phase equilibrium studies have been made in the range 150°–1000°C and pressures of 2500–25,000 psi. Contrary to earlier work the pseudo-wollastonite-wollastonite inversion is fairly easily reversible even in the absence of water; the inversion temperature (also checked by extrapolation from the $CaSiO_3—SrSiO_3$ system) is 1120° ± 10°C. A p-t curve for the decomposition

of xonotlite to β-wollastonite and vapor has been determined; the equilibrium temperature ranges from 400°C at 5000 psi to 420°C at 20,000 psi. It has also been shown that in the low-temperature region xonotlite gives place first to a $CaSiO_3$-hydrate first described by Flint, McMurdie, and Wells as "Extra Lines B" at ~260°C (at 20,000 psi) and then to tobermorite at ~220°C. No parawollastonite has been encountered in any of these runs. The equilibrium diagram for the system $CaSiO_3$—$SrSiO_3$—H_2O shows that the wollastonite structure will admit very little Sr^{++} (<5%), whereas there is a complete solid solution between the two pseudo-wollastonite phases. A new phase in this system, possibly the same as an un-named mineral found by Tilley at Skye, is described.

IS THERE ROOM FOR LIBERAL EDUCATION COURSES IN THE GEOLOGY CURRICULUM?

Fred M. Bullard
The University of Texas, Austin, Texas

The increase in the subject matter of geology in recent years and the need to add more courses to cover these fields have crowded the geology curriculum to the extent that many of the liberal-education courses formerly included are now omitted. Assuming that a liberal education is desirable for a well-rounded geologist, the colleges are faced with the possibility of: (1) lengthening the period of study from 4 years to 5 years, or even more, in order to include such courses, (2) leaving out some of the geology courses to make room for liberal-education courses, (3) setting up entrance requirements which would insure that much of the liberal education will be taken in high school, or (4) some combination of the above proposals.

The emphasis today on graduate work in geology is largely an application of (1). Unfortunately, in many cases the geology content is increased without any increase in liberal-education content. The problem seems to narrow itself down to a consideration of "how much" geology is needed and "how much" liberal education is needed in a balanced curriculum. If these points can be answered the length of the course of study is automatically determined. Evidence supports the conclusion that much of the liberal education as well as the basic fundamentals, especially in mathematics and the sciences, can be done effectively in high school. The extent to which this can be done will correspondingly shorten the length of time required in college.

PETROLOGY OF GYPSUM-ANHYDRITE DEPOSITS IN SOUTHWESTERN INDIANA*

Wayne M. Bundy
Indiana Geological Survey, Indiana University, Bloomington, Ind.

Crystalloblastic anhydrite is present in Middle Mississippian dolomitic limestones in two phases: (1) gneissic porphyroblastic anhydrite in extensive lenticular beds, and (2) a later stage of porphyroblasts and veins formed penecontemporaneously with dolomite rhombs. Evidence indicates that magnesium sulfate solutions acting upon calcium carbonate may have been responsible for the anhydrite-dolomite association. Magnesium within the gypsum lattice may have been released upon the conversion of primary gypsum to anhydrite and formed dolomite.

Textural characteristics of the gypsum indicate that it was derived by hydration from recrystallized anhydrite. Although primary gypsum could not be recognized as such, much of the calcium sulfate was probably precipitated as gypsum.

Solubility curves of calcium sulfate and its hydrates show that conversion of anhydrite to gypsum is a reconstructive process. The intermediate phase (hemihydrate) undergoes displacive transformation upon conversion to gypsum. Minor quantities of hemihydrate in rock slices containing transition

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zones of anhydrite-gypsum are indicated on x-ray spectrometer curves. Included sodium chloride in anhydrite, released upon gypsification, may have provided solutions of sufficient concentration to permit the dissociation of gypsum to hemihydrate.

For gypsification to take place, space must be available for water in addition to space occupied by anhydrite; this total volume (anhydrite plus water) is greater than the space occupied by the resultant gypsum. Distortion of rocks may follow gypsification of anhydrite but is the result of directional forces exerted by crystals within gypsum veins rather than total volume expansion.

EXPLORATION OF THE PETROGRAPHIC CONSTITUTION OF FOUR OHIO COALS*

Gilbert H. Cady and Gilbert E. Smith
Ohio Division of Geological Survey, Orton Hall, Ohio State University, Columbus 10, Ohio

Since July 1953 an exploration of the petrographic constitution of four Ohio coals, Meigs Creek (No. 9), Pittsburgh (No. 8), Middle Kittanning (No. 6), and Clarion (No. 4A), has been underway at Columbus. The methods of investigation have been restricted almost entirely to those of polished surface technique largely because the investigation included a study of broken coal as well as of columns and cores. The investigation involved the preparation of megascopic bed profiles in terms of the banded ingredients and mineral matter, these generalized profiles indicating considerable differences in the composition of the four beds. Profiles were also made of whole beds or selected portions of bed on the basis of microscopically identified constituents or macerals. Such profiles further accentuated the differences among the coals, particularly with respect to the duller portions of the beds with the character and degree of dullness being determined by varying quantities of exinite, micrinite (opaque matter) and mineral matter and decrease in content of microvitrain and vitrinite as represented by the humic degradation matter. Studies of broken coal produced by dropping or representing screen sizes of mine run coal indicated that the physical character particularly hardness and toughness of the so-called lithotypes and microlithotypes exercised an important influence upon the petrographic composition of the various sizes. It seems probable where it is essential to maintain uniformity of product prepared for special use, consideration of the petrographic composition of the coal in planning preparation procedures would have a beneficial result.

TRUCK-MOUNTED SPECTROGRAPHIC LABORATORY FOR USE IN GEOCHEMICAL EXPLORATION—A PRELIMINARY REPORT

F. C. Canney, A. T. Myers, and F. N. Ward
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

A mobile spectrographic laboratory to demonstrate the feasibility of using and transporting spectrographic equipment in the field and to supply rapid on-the-spot analytical data is housed inside a 7- by 12-foot insulated and air-conditioned van-type truck body and carries complete equipment for making qualitative and quantitative spectrographic analyses of geological materials. The spectrograph is a fixed-position 1.5-meter grating instrument in a Wadsworth stigmatic mounting, which records the region from 2063A to 4837A in the second order on a 20-inch strip of film. Companion units include a projection-type comparator densitometer, film processor, and other accessory equipment. Trailer-mounted motor generators supply 230 volts d-c for the arc-source unit and 115 volts a-c for lights and accessories.

In June 1955 the truck-mounted laboratory was driven 525 miles to a field project near Eureka, Utah. During the trip, all the equipment remained in good adjustment, and the laboratory was ready for operation in less than 2 hours after arrival.

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* Presented with the approval of the Chief, Ohio Division of Geological Survey

Because of the large number of elements that can be determined from a single spectrogram, the truck mounted spectrographic laboratory should be useful in the early stages of a geochemical exploration project to determine diagnostic suites of elements, and later to guide the day-to-day sampling.

BASIN RANGE STRUCTURE AND THE ROBERTS MOUNTAINS OVERTHRUST, MINERAL HILL QUADRANGLE, NEVADA

Donald Carlisle and Clemens A. Nelson
Department of Geology, University of California, Los Angeles, Calif.

The Roberts Mountains overthrust is now known to extend over much of north-central Nevada. In the Sulphur Springs Range western facies Ordovician to Devonian shales, cherts, limestones, and quartzites of the upper plate lie upon uppermost members of the eastern facies Devonian Nevada formation. The overthrust has been folded mainly along north-trending axes; bedding in the underlying carbonate rocks parallels the overthrust surface. Some complex structures in the upper plate likewise appear related to post-thrust folding. Locally overthrust folds are overt urned strongly to the east indicating eastward transport roughly along the direction of original thrusting inferred from facies distribution. South of the quadrangle Permian limestone and conglomerate unconformably on contorted western facies Vinini formation are overturned to the east probably in a similar overfold, but these beds may have been deposited after original thrusting. Later thrusting related to folding is suspected but not proved.

The pattern developed with thrusting and folding has controlled basin range structure. Weak northeasterly and northwesterly vertical faults, probably complementary, developed mainly in the lower plate. Northerly high-angle faults remarkably parallel to fold axes cut these faults creating elongate graben and horsts en echelon within the range. Thus east boundary faults near the south end of the range become west boundary faults near its north end. Strong renewal of movement has occurred along some northeasterly faults, and recurrent movement accompanied by cumulative tilting continues along northerly faults.

INTRAFORMATIONAL CONGLOMERATE BY MIXED SEDIMENTATION IN THE UPPER CRETACEOUS OF THE ROC-DE CHÈRE CHAINS OF HIGH SAVOY, FRANCE

Albert Carozzi
Dept. of Geology, University of Illinois, Urbana, Ill.

The glauconitic and sandy limestone sequence, which in most places represents the Upper Cretaceous transgression throughout the High Calcareous Alps of the High Savoy, gives way, in the Roc-de-Chère region, to a 3- to 4-foot bed of conglomerate containing curiously shaped pebbles of fine-grained limestone scattered in a glauconitic matrix.

Three distinct limestone types may be distinguished in the conglomerate on the basis of shape, dimension, and induced flow structures (from base to top): (1) contorted streaks, (2) larger irregular pebbles with highly deformed matrix inclusions, and (3) still larger subrectangular chunks with slightly deformed matrix inclusions.

The microscope reveals, both in the pebbles and in the matrix, well-developed flow structures evidenced, for instance, by the elongated arrangement of quartz grains and by the arrangement of deformed *Globotruncana* tests.

A tentative explanation might suggest a mixed sedimentation in which beds of plastic calcareous muds and glauconitic sands were alternately deposited. Reworking phenomena intensively stretched and mixed the freshly deposited beds; however, intensity of deformation decreases upward as depth of water increased during transgression.

Such a sediment may be classified as a special type of intraformational conglomerate formed under wave action when beds were still plastic.

DEVELOPMENT IN POTASSIUM-ARGON DATING

D. R. Carr and J. L. Kulp
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

An effort has been made to define some of the more elusive variables in the potassium-argon age method. Problems of complete argon retention during the history of the mineral, complete release during fusion and equilibration of the rock argon and spike to assure accurate measurement have been considered. Radioactive A^{37} has been employed as a tracer. Tests in which known quantities of argon were sealed in capillary tubes, buried in a rock sample, and then fused yielded results which point to complete gas recovery when no flux is used during fusion.

In an effort to bring more data to bear on the argon-retention problem, calibration runs have been carried out using samples which gave lead-uranium ratios. Feldspar-mica comparisons have been made for five mines in the pegmatite swarm around Spruce Pine, North Carolina, as well as several measurements on the host rocks of the area, using a branching ratio of .123 and a λ_B of $.476 \times 10^{-9} yr^{-1}$. The mica ages for the pegmatites agree with the uranium-lead age of 350 ± 20 m.y. The feldspars which are consistently lower have retained from 65 to 85 per cent of the argon formed in them. The host rock ages which must be considered minimal are clearly older than the pegmatite micas. Therefore, an earlier Precambrian cycle of metamorphism is indicated.

CRYSTAL STRUCTURE OF LUDWIGITE, $Mg_2Fe'''BO_5$

Jair Carvalho da Silva, Joan R. Clark, and C. L. Christ
U. S. Geological Survey, Washington 25, D. C.

The structure of ludwigite was worked out by Takeuchi, Watanabe, and Ito in 1950 from packing considerations and relatively crude intensity data. The writers have re-examined this structure using quantitative intensity data derived from crystals from Crestmore, California, which have the composition $(Mg_{1.55}\ Fe''_{0.15})\ (Fe'''_{0.54}\ Al_{0.41}\ Ti''''_{0.04})\ BO_3O_2$ (analyst, A. Vilisidis, U. S. Geol. Survey). The essential correctness of the structure of Takeuchi and others was established. Data obtained in the present study are:

a = 9.25 Å ± 0.2% Orthorhombic — *Pbam*
b = 12.21 Å ± 0.2% Density (calc.) = 3.60
c = 2.988 Å ± 0.2% Density (obs.) = 3.64
Cell contents: 4 $[(Mg, Fe'')_2(Fe''', Al)\ BO_3O_2]$
Crystals black, prismatic [001]

Electron-density projections along the short *c* axis yield the following parameters:

Atom	*x*	*y*	*z*	No. Atoms
O_1	0.36_1	0.45_9	0	4
O_2	0.11_0	0.14_2	0.500	4
O_3	0.12_5	0.35_6	0	4
O_4	0.39_4	0.07_8	0.500	4
O_5	0.36_0	0.26_9	0	4
Mg_1	0	0	0.500	2
Mg_2	0	0.281	0.500	4
Mg_3	0.500	0	0	2
(Fe‴,Al)	0.255	0.115	0	4
B	0.27	0.37	0	4

The following bond lengths were obtained:

$(Fe''', Al)—O_1$	2.1$_9$ A	$Mg_2—O_2$	1.9$_8$ A
$(Fe''', Al)—O_2(2)$	2.0$_3$	$Mg_2—O_3(2)$	2.1$_0$
$(Fe''', Al)—O_4(2)$	2.0$_3$	$Mg_2—O_4$	2.0$_0$
$(Fe''', Al)—O_5$	2.0$_2$	$Mg_2—O_5(2)$	2.0$_4$
Mg_1 —$O_1(4)$	2.0$_3$	$Mg_3—O_3(2)$	2.1$_1$
Mg_1 —$O_2(2)$	2.0$_1$	$Mg_3—O^4(4)$	2.0$_1$
B—O (av. of 3)	1.4$_4$	O—O(all)	>2.7

Although the unit-cell parametes assigned to the cation positions are essentially correct, the relative distribution of the Mg'', Fe'', Fe''', and Al''' among these positions is not yet established. This aspect is important to an understanding of the fundamental nature of the solid-solution problem. Difference fourier mapping is being carried out in an attempt to settle this point.

PILLOW BRECCIA AND ITS SIGNIFICANCE, MT. DESERT ISLAND, MAINE

Carleton A. Chapman
University of Illinois, Urbana, Ill.

Breccias, with a structure resembling pillow lava, are well developed on Mount Desert Island, Maine. They consist of pillow-shaped fragments of diabase or gabbro in a matrix or vein network of granitic material. This type of breccia deserves a special name, and the descriptive term pillow breccia is here proposed.

The breccias may occur as clean-cut dikelike masses or as irregular lenslike bodies in banded gabbro indicating that the breccia fragments are derived from intrusive masses rather than volcanic flows.

Abundant and compelling evidence that the breccias have formed by localized replacement of basic rock by granitic material, derived from near-by magmatic bodies, is based largely upon geometrical relations of both microscopic and macroscopic scale. Shape, arrangement, textural zoning, and relic character of the breccia blocks; as well as shape, arrangement, mineral variation, and textural heterogeneity of the granitic matrix veins indicate that little if any magma entered the brecciated rock.

It seems likely that the granitic material, whatever its nature, moved along lanes of structural weakness in the basic rocks. Evidence for such a structural control is found principally in the nature and degree of replacement of different rock types (gabbro and diabase) and the replacement pattern and its relation to the structure of the replaced rock.

Pillow breccias have been used successfully to predict and help establish the shape and internal structure of basic igneous masses.

UNUSUAL TYPE OF RIPPLE MARK

Philip A. Chenoweth
School of Geology, University of Oklahoma, Norman, Okla.

Ridges, resembling large ripple marks in every respect, have been studied in the bed of Wewoka Creek, Seminole County, Oklahoma. In amplitude, averaging 4.25 inches, wave length, averaging 25.5 inches (index: 6.0), and symmetry they are quite similar to marine-formed pararipples. These are definitely stream (current) formed and are oriented parallel to one another and to the direction of stream flow on a wide bar extending nearly across the channel. Exposure measures about 100 feet in width and length. The ripple troughs are coarse (gravel) material to a depth of 3–4 inches; the crests are of finer (silt and clay) material, a feature supposedly diagnostic of wave-formed ripples. It is supposed that the bar is part of a much larger set of metaripples and the ripples themselves are

the result of sculpturing by a waning current. The possibility that some poorly exposed ancient pararipples could have had a similar origin should lead to care in interpretation.

CRYSTAL CHEMICAL STUDIES OF URANIUM OXIDE HYDRATES

C. L. Christ and Joan R. Clark
U. S. Geological Survey, Washington 25, D. C.

A number of uranium (VI) oxide hydrates, some of which form solid solutions with PbO and BaO, and perhaps CaO, have been investigated. These include becquerelite, schoepite, billietite, masuyite, fourmarierite, and vandendriesscheite. These have related structures that differ in detail but are all based upon a pseudo-hexagonal arrangement of UO_2^{++} ions co-ordinated by OH^- ions. Linear, vertical UO_2^{++} ions are linked together into infinite horizontal sheets of OH^- ions, with the sheets held together in the vertical direction by water molecules, or in the barium- or lead-containing minerals also by ions of these metals. The idealized sheet structure is similar to that found for UO_2F_2 by Zachariasen in 1948. The general formula for these compounds $xMeO \cdot yUO_3 \cdot zH_2O$ may be rewritten as $xMe(OH)_2 \cdot yUO_3(OH)_2 \cdot (z\text{-}x\text{-}y)H_2O$. The structure results are in agreement with the observed perfect (001) cleavage and zeolitic nature of the water in excess of that required for the hydroxyl groups.

BAHAMA BANKS WEST OF ANDROS ISLAND

Preston E. Cloud, Jr.
U. S. Geological Survey, Washington 25, D. C.

Peak salinity and chlorosity characterized the middle bank waters west of northern Andros Island in May 1955. Alkalinity was correspondingly low. Salinities over 39‰ prevailed, 43‰ was common, and 46‰ was recorded. Chlorosity ran 21 to 26 g Cl^-/L. Alkalinity fell from 2.3–2.6 milliequivalents oceanward to 1.76 at midbank.

These values, and aragonite mud distribution, indicate $CaCO_3$ precipitation from hypersaline waters west of Andros much as outlined by C. L. Smith (Jour. Marine Research, 1940). The combination of low alkalinity with high salinity and temperature points to a low value for the solubility product constant of $CaCO_3$ in sea water.

Daytime pH of the bank waters averaged 8.1, and Eh clustered around +400 millivolts. Sediment Eh fell from +460 in oceanward limesands to −190 in limemuds, with pH 6.9 to 7.8. Low redox potentials characterize the muds, which are extensively pelleted and grade oceanward to limesands. Downward in the cores pH tends to rise, and Eh tends to fall. Insolation seems principally responsible for sediment heat, with biochemical effects subordinate.

Porous limestone was found beneath less than 10 feet of sediment at widely separated localities across the bank. In recovered samples calcite replaced aragonite. Shells of mollusks not found living in the area rest upon the rock floor, which evidently appreciably antedates the present sedimentary cycle.

The biota is limited in variety, particularly of organisms normally found as megafossils. Turtlegrass, algae, sponges, and burrowing organisms, however, are generally common.

Laboratory studies will emphasize calcium carbonate equilibria relationships and the origin, diagenesis, and biotal associations of nonclastic carbonate rocks.

GENERAL EDUCATION IN RETROSPECT

George V. Cohee
U. S. Geological Survey, Washington 25, D. C.

A few years ago the writer was associated with the Department of Geology in one of the universities in the Southwest when a program of general education was being introduced in the Liberal

Arts College of the University. It was the responsibility of the staff of the department to formulate a curriculum and plan of instruction by which the general-education program could be interwoven into the curricula of the college.

One of the big obstacles was the possible modification of the existing geology curriculum and supporting courses. Most of the students who receive degrees in geology of that university go to work for oil companies. The members of the staff felt a strong obligation to provide adequate training in geology to these students when some of the industry's representatives were requiring a minimum of 50 hours of geology before the students would be considered for employment. Following numerous interdepartmental meetings and discussions, it appeared to the writer that not all the courses fundamental in the training of the geologist could be given in a 4-year curriculum that included the proposed general-education courses.

In view of the country's need for technological advancement and the apparent shortage of students trained in certain technical fields, should the curriculum for geology majors be sacrificed for a general-education program?

COLOR CENTERS IN THE α-QUARTZ CALLED AMETHYST

Alvin J. Cohen
Mellon Institute, Pittsburgh, Pa.

The absorption spectra of six amethyst specimens from different regions are compared in the range 200–1700 mμ. All the amethyst exhibited absorption bands centered near 340, 540, and 950 mμ. Certain specimens studied in the 200–300 mμ spectral region exhibited bands variously at 214, 225, 250, and 266 mμ. The bands at 225, 266, 340, 540, and 950 mμ are produced or enhanced by x-irradiation and have the attributes of color centers. The 340 mμ band (using normal light) is anisotropic and centered at 360 mμ for light vibrating along the *c* axis; comparison of the spectrum using the extraordinary and the ordinary ray shows the light absorption of the former to be greater. The green color (due to an absorption band at 725 mμ) remaining after heat bleaching of a Brazilian amethyst appears to be associated with a separate microscopic phase oriented in the quartz.

Results of emission analyses for trace impurities in all the specimens investigated are given and compared to those of an x-irradiated fused silica and a solarized complex silicate glass that exhibit similar color centers. A comparison is also made of the impurity contents of natural and synthetic quartzes that turn smoky upon x-irradiation. The relationships among color centers, impurit content, and optical twinning in amethyst are discussed.

NORTH AMERICAN PALEOZOIC CHITINOZOA*

Charles Collinson and Howard Schwalb
Illinois Geological Survey, Urbana, Ill.

Newly reported occurrences from Ordovician, Silurian, and Devonian strata in North America suggest that Chitinozoa may have great potential for use as stratigraphic index fossils. A reconnaissance of wells, outcrops, field notes, and literature has yielded 19 geographic occurrences and leads us to believe that these microfossils are widely distributed and abundant in the Paleozoic. Study of a complete Silurian-Devonian well core in White County, Illinois, has shown chitinozoans in three zones and representing two distinct faunules.

The taxonomic position of the Chitinozoa is discussed, and it is concluded that the microfossils represent an extinct order of rhizopod protozoans. All previously recorded genera are briefly described, and two new genera are proposed. Eleven new species are described and illustrated.

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ENGINEERING PROPERTIES OF BEDROCK WEATHERING PRODUCTS IN THE SOUTHEASTERN PIEDMONT

William V. Conn and George F. Sowers
Corps of Engineers, P. O. Box 1889, Atlanta, Ga.

The gneisses, schists, and associated crystalline rocks of the Southeastern Piedmont have been subjected to the rapid chemical weathering typical of a warm humid climate and have broken down to form the deep residual soils. Analyses of the soils indicate alteration of the original minerals to secondary minerals, largely kaolinite, illite, vermiculite, quartz, gibbsite, biotite, and iron oxide. Feldspars, which constitute a large percentage of the original minerals, are often completely altered even adjacent to unweathered rock. The normal soil profile, produced by varying degrees of weathering with depth, consists of red, sandy to silty surface clays, grading into micaceous sandy silts and silty sands, which in turn become gradually less altered, with inclusions of unweathered rock, as the sound rock surface is approached.

The soils produced by this type of weathering present unique construction and engineering problems. The bands and lenses of varying types of soil material which are inherent from the gneissic structure of the parent rock, and the varying degrees of alteration present in each material, make foundation-analysis procedures by normal soil-mechanics methods difficult. Foundation design must consider contorted bands of soft, partially altered minerals which complicate bearing capacity and settlement computations. Construction procedures must also be planned with an understanding of soil and rock characteristics to prevent costly and often dangerous slope failures in excavations.

NOMENCLATURE AND RECOGNITION OF IGNIMBRITES

Earl Ferguson Cook
Department of Geology and Geography, University of Idaho, Moscow, Idaho

Pyroclastic sheets of probable *nuée ardente* origin have been called sand flows, tuff flows, welded tuffs, and ignimbrites. Sand flow and tuff flow, however, do not express the magnitude of the phenomena involved; the flow concept is hardly applicable to the extremely rapid, all-sided, turbulent expansion of an incandescent cloud. The use of welded tuff to describe a *nuée ardente* deposit is equally unsatisfactory, since such deposits may be wholly or in part nonwelded. Ignimbrite (deposit of a fiery cloud), unlike the other three terms, is adequate. Although ignimbrite was first defined both as a rock and as a rock unit, its use could profitably be restricted to the latter. The Wentworth and Williams pyroclastic classification, together with terms describing the degree of welding and the chemical composition (*e.g.*, strongly welded rhyolitic crystal tuff), is sufficient for description of the rock types found within an ignimbrite.

Ignimbrites may be distinguished from lava flows by great extent, horizontal depositional surface, lack of vesicles, presence of compaction but not flow structures (foliation without lineation, for example), generally low specific gravity decreasing upward, abundance of glass shards, as well as the possible presence of incoherent basal ash, lithic fragments throughout the mass, and upward decrease in hardness. Ignimbrites may be distinguished from air-fall and waterlaid tuffs by absence of bedding, lack of sorting, presence of rude prismatic jointing, compaction structures, and welding.

ARTHROPOD ZONES OF THE UPPER CARBONIFEROUS COAL MEASURES OF THE CANADIAN MARITIMES*

Murray J. Copeland
Geological Survey of Canada, Victoria Museum, Ottawa, Canada

More than seventy species of arthropods are known to occur in the Upper Carboniferous strata of the Maritime Provinces of Canada. They are included in four classes: Crustacea, Arachnoidea,

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Diplopoda, and Insecta. Specimens have been found in gray and black shales and limestones of the Canso, Riversdale, Cumberland, and Pictou groups, some of which are associated with coal seams. These strata are interpreted as fresh and brackish water deposits.

Each of these four major stratigraphic groups can be distinguished by its arthropod fauna. The lowermost group, the Canso, is divisible into three zones. The lower part of the Canso contains a brackish water fauna and the upper part a fresh-water fauna. The Riversdale group has an arthropod fauna closely similar to that of the Cumberland group, but can be differentiated from the Cumberland by the presence of a few distinctive species. The uppermost group, the Pictou, contains many species not found in the other stratigraphic groups.

The arthropods from these Upper Carboniferous strata resemble those from the Namurian and Westphalian deposits of western continental Europe. Only a few long ranging species are common to the Upper Carboniferous rocks of the Maritimes and strata of similar age elsewhere in North America.

PENNSYLVANIAN ROCKS AND SPORE FLORAS FROM THE SUBSURFACE WARRIOR BASIN, MISSISSIPPI

Fred Cropp, R. M. Kosanke, and H. R. Wanless
University of Illinois and State Geological Survey, Urbana, Illinois

Although outcropping Pennsylvanian strata of the Black Warrior basin in Alabama aggregate only about 3700 feet, borings in northeastern Mississippi suggest a thickening to more than 8000 feet within three counties of their outcrop under Cretaceous sediments. Wells have entered Pennsylvanian rocks as far as two counties south of the maximum penetration in Clay County, beyond which Ordovician dolomites are found beneath the Cretaceous. Samples from three wells in Monroe, Calhoun and Clay counties represent respectively 2105, 4736 and 8013 drill feet of Pennsylvanian strata. Well cuttings in each yield coal chips which may be separated from associated shale and sandstone by specific gravity.

The Young-Henderson well in Clay County yields coal from 50 different samples or adjacent groups of samples, suggesting at least 50 coal beds. Although the amount of coal recovered from each zone is generally less than one gram, spores have been isolated by maceration, and it is believed they can be used for correlation. The highest coal zone in the Clay County well contains *Denso-sporites* which is not known to extend above the Tradewater of Illinois or the top of the Pottsville or basal Allegheny of the Appalachian field. *Cirratriradites maculatus* was also observed in this highest coal zone and is not known to occur above the Tradewater in Illinois. Thus the strata of Pottsville age suggests an aggregate of at least 8000 feet. The coal succession in Mississippi seems likely to yield the most complete succession of Pottsville age spore floras in the United States.

ALLEGHENY-LOWER CONEMAUGH STRATIGRAPHY IN NORTHERN WEST VIRGINIA

Aureal T. Cross and Mart P. Schemel
West Virginia Geological Survey and West Virginia University, Morgantown, W. Va.

Five locally minable but highly variable coal seams and several marine zones in Allegheny and Lower Conemaugh strata of the Northern Panhandle of West Virginia and adjacent areas in Ohio and Pennsylvania have been the basis for interstate correlation of these strata for many years. Knowledge of faunal assemblages for ready and accurate identification of the marine zones has not been established.

Recent studies of plant microfossils from coal samples taken from core tests, oil-well cuttings, and outcrops have made possible the distinguishing of Lower and Middle Kittanning coals from each other and these two from the Freeport coals. The Upper and Lower Freeport are usually individually identifiable and these are both distinctive from Brush Creek and Bakerstown Assemblages.

Extensive study of surface sections together with detailed analyses of numerous sets of well-cuttings have resulted in outlining the general extent of five principal coals and shows them to change rapidly in thickness within very local areas. Some problems of nomenclature or/and correlation remain unsolved because of the apparent misidentification of Kittanning, Freeport and Mahoning coals, between this and the type areas in Pennsylvania and Ohio and ambiguity of coals at type localities. Several additional coal horizons have thick coals locally to further confuse the correlation.

Several additional marine horizons are now recognized. Marine conditions appear to have returned between accumulation of most coal seams in the area. Some of these were minor pulsations, often two or three for each major invasion, *e.g.*, Kittanning, Freeport, Brush Creek, Cambridge and Ames.

VIOLIN BRECCIA IN TRANSVERSE RANGES, CALIFORNIA

John C. Crowell
Department of Geology, University of California, Los Angeles, Calif.

The Violin breccia, an unusual sedimentary formation, has a stratigraphic thickness of about 27,000 feet but extends along the strike for a maximum distance of only 4000 feet. The formation crops out as a band adjacent to the San Gabriel fault in the Transverse Ranges between Los Angeles and Bakersfield, California, and accumulated during the late Miocene and Pliocene. Throughout its extent it grades abruptly into finer-grained marine and nonmarine Ridge Basin strata on the northeast. This sharp facies change defines a lithologic contact which trends nearly normal to the bedding instead of nearly parallel.

Near the San Gabriel fault the breccia consists of a rubble of angular and subangular gneissic and granitic clasts up to 6 feet in diameter embedded in a muddy matrix. Bedding here is indistinct, but within 500 feet to the northeast it is well defined where tongues of such unsorted debris extend between sandstone and graywacke layers which are commonly graded, convoluted, or current-bedded. The formation accumulated as talus or fan deposits at the base of the San Gabriel fault scarp and was derived from gneissic terrane to the southwest beyond the fault. The great thickness of the breccia and the long duration of its accumulation indicate intermittent or continuous rejuvenation of the fault scarp from some time in the late Miocene until late in the Pliocene.

STRUCTURES RELATED TO THE 'QUODDY TIDEWATER PROJECT, MAINE AND NEW BRUNSWICK*

L. M. Cumming
Geological Survey of Canada, Ottawa, Canada

The 'Quoddy project is a proposal to utilize the geological configuration of two shallow marine embayments (Cobscook Bay, Maine, and Passamaquoddy Bay, New Brunswick) by restoring the structural trends of Silurian formations and harnessing the region's high tides to provide a head for hydroelectric power.

Northeast Appalachian trends are locally modified by a combination of folding and faulting that has resulted in the juxtaposition of two bays each with a different structurally controlled bay mouth. E. S. Bastin has interpreted Cobscook Bay as a succession of Silurian sedimentary and volcanic rocks folded anticlinally, plunging northeast, and with grabenlike boundary faults.

A major wrench fault separates Cobscook Bay from Passamaquoddy Bay. It trends north-northwest along the St. Croix channel and is assumed to have continuity for 30 miles from Campobello Island to Oak Bay, where its apparent minimum horizontal displacement is 1½ miles. Deer Island, on the east side of the fault, has the form of a large-scale drag fold, which indicates its relative displacement to the north. The Silurian rocks of the north shore of Passamaquoddy Bay are at the margin of the St. George granite, and the structures of the Silurian succession are those produced in the lower part of down-folded eugeosynclinal deposits. Deformed fossils have northeast axes of maximum elongation.

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IMPORTANCE OF NOVARUPTA DURING ERUPTION OF MT. KATMAI, ALASKA, IN 1912

Garniss H. Curtis
U. S. Geological Survey and University of California, Dept. Geological Sciences, Berkeley, Calif.

Isopachous maps have been prepared for the various ash layers from the eruption of 1912. White pyroxene-free rhyolite pumice characterizes the first explosive phase, but poor exposures preclude an accurate isopachous map of this layer. However, the greatest thickness and largest pumice fragments occur on Knife Peak, about 5 miles northwest of Mt. Katmai, suggesting that Mt. Katmai was not the source, for the wind was from the northwest at the start of the eruption. Later ash layers are marked by gray, pyroxene-bearing pumice. With the possible exception of the dark uppermost thin ash layer, which has been widely stripped, all these originated at Novarupta, about 6 miles west of Mt. Katmai.

Only pyroxene-bearing pumice occurs on top of the sandflow in The Valley of 10,000 Smokes northwest of Mt. Katmai. Adjacent to the sandflow on the lower slopes of Knife Peak, however, the basal pyroxene-free pumice layer occurs, indicating that emplacement of the sandflow followed ejection of the pyroxene-free pumice.

The eruption of Mt. Katmai itself was probably a minor event closing the activity in 1912 and is attested only by the dacite cinder cone on the crater floor and dark ash on the crater rim which may be correlative with the uppermost ash layer found elsewhere. Still unexplained is an outcrop within the crater rim of steeply dipping welded tuff deposited after collapse of Mt. Katmai.

PETROGRAPHIC CHARACTERISTICS OF SANDSTONES OF THE PENNSYLVANIAN OF THE CENTRAL APPALACHIAN COAL FIELD

E. C. Dapples and R. M. Mitchum
Northwestern University, Evanston, Ill.

Pennsylvanian sandstones associated with coals of the Lee group in the Central Appalachian Coal Field constitute a continuous petrographic series ranging from graywackes, in the extreme eastern part, to quartzose varieties which predominate in the west, bordering the Nashville dome.

Rocks classified as graywackes have an average composition of 50% quartz, 10% feldspar (70% microcline and 30% sodic plagioclase) 20% matrix (clay, sericite, chlorite, quartz, carbonaceous matter) and 20% rock fragments. Subgraywackes average 72% quartz, 26% matrix of finely divided quartz, sericite and carbonaceous matter, 10% rock fragments, and less than 1% feldspar. Quartzose sandstones average 90% quartz grains, 5% matrix (sericite and clay), and 5% rock fragments. Rock fragments are quartzite and shale.

Lateral gradation exists between graywackes and subgraywackes, and vertical as well as lateral gradation is observed between subgraywackes and quartzose sandstones.

Each petrographic variety displays paragenetic relationships among minerals, apparently reflecting diagenetic environmental conditions. Graywackes show fresh microcline, but altered sodic plagioclase. Silica is unstable as indicated by the highly frayed edges of quartz, but potash rich minerals are stable, and others, such as sericite develop from the clay matrix.

Quartz in subgraywackes shows secondary development which is inhibited by the presence of clay matrix. In this rock silica is stable and where quartz grains are in contact overgrowths form. Potash minerals particularly muscovite grow as large secondary crystals in the clay matrix. Carbonate cement, generally iron rich, replaces quartz grains, and where concentrated develops concretions. Local calcite cement is replaced by secondary silica during time of development of quartz overgrowths.

Quartzose sandstones show tendency to increase in carbonate content (primarily calcite) until carbonate preponders over quartz. In such cases quartz appears unstable and is being replaced by calcite. Where carbonate cement is feeble quartz overgrowths are very common and interlocking of grains results.

PRE-CRETACEOUS STRUCTURE IN WESTERN GUERRERO, MEXICO*

Zoltan de Cserna and Jerjes Pantoja
Instituto Nacional para la Investigación de Recursos Minerales and Instituto de Geología; Ciprés 176, México 4, D.F., México

Reconnaissance mapping in the Balsas River basin and in the Sierra Madre del Sur revealed a metamorphic sequence, covered by Albian and possibly older sediments. The metamorphics consist of greenstones, phyllites, mica schists, and gneiss.

West of Teloloapan which lies north of the Balsas River, the greenstone-phyllite series has N. 35° E., 30° N. foliation. South of Tierra Colorada in the valley of the Papagayo River, the foliation in biotite schist is N. 20° W., 45° S. Farther south, just north of Acapulco, the foliation in gneiss trends northwest.

The greenstone-phyllite series, north of the Balsas River, is cut by Tertiary dioritic intrusives, whereas the mica schist-gneiss series, between the Balsas River and the Pacific Coast, is intruded by granites. Signs of granitization were not observed; however, the granite near Acapulco may be the result of that process. The granodiorite intrusive at Tierra Colorada is doubtless Tertiary.

The mica schist-gneiss series shows increasing metamorphism toward the south suggesting relation to the Lower Paleozoic metamorphics of Chiapas and southern Oaxaca, and not to Upper Cretaceous metamorphics of Baja California. The greenstone-phyllite series appears to be independent from the former and progressively metamorphosed toward the north. This is considered inciative of Appalachian age as it lies along the trend of the Permo-Triassic orogenic belt. Further mapping of significant details is planned for the next several years.

SOIL-MECHANICS PROPERTIES OF WEATHERED VOLCANIC ROCKS IN HAWAII

Don U. Deere and T. H. Thornburn
Talbot Laboratory, University of Illinois, Urbana, Ill.

Construction operations in the Hawaiian Islands have revealed the unusual engineering characteristics of residual soils derived from volcanic rocks. Weathering in the tropical to subtropical climate has proceeded to depths of more than 100 feet in some places. X-ray diffraction studies show that the residual soils are essentially amorphous material with little or no identifiable clay mineral. This composition is similar to the clay from Mexico City which is also derived from volcanic materials.

The natural water contents of the Hawaiian residual soils are high, ranging from 50 to 300 per cent based on oven-dry weight. One peculiar property noted is the change in the Atterberg limits upon drying from the natural to the air-dry state. The values of the liquid limit and the plasticity index decrease by as much as 100 per cent.

The compaction characteristics are also dependent upon the moisture conditions. Laboratory values of dry density obtained from tests starting with air-dry material are from 20 to 50 per cent greater than values obtained in the field using the soil at its natural water content. Most of these soils appear to be highly sensitive to disturbance of their natural structure. The unconfined compressive strength of undisturbed samples may be 9 or more times as great as the strength of samples which have been remolded at their natural water contents.

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MODE OF OCCURRENCE OF URANIUM IN THE CHATTANOOGA SHALE

Maurice Deul
U. S. Geological Survey, Washington, D. C.

The Chattanooga shale, an abnormally uraniferous marine carbonaceous shale of Late Devonian age, has been studied to determine the relationship of uranium to gross organic and mineral constituents. Mineral-rich, organic-rich, and uranium-rich fractions have been obtained mechanically from a shale sample containing 0.009 per cent uranium and 13.7 per cent carbon.

Separation of shale components after ball-mill grinding in a mixture of water and kerosene for several hundred hours yielded a mineral concentrate containing 0.0035 per cent uranium and 4.7 per cent carbon, an organic concentrate containing 0.0038 per cent uranium and 39.8 per cent carbon, and a middlings fraction, consisting of the finest particles, assaying 0.019 per cent uranium and 9.1 per cent carbon.

With increased grinding time more uranium has been liberated from the shale components. The middlings fraction from a sample milled for 1361 hours contained 0.031 per cent uranium and 26.7 per cent carbon. This fraction, consisting of less than 8 per cent of the total material, contained more than 24 per cent of the uranium.

These experimental data indicate that uranium in the Chattanooga shale exists largely as a colloidal phase dispersed through the organic matrix and that most of the uranium is not now combined with the organic material or with the minerals. These conclusions are confirmed by other experiments where colloidal fractions markedly enriched in uranium were obtained by air elutriation of air-jet pulverized shale and by dialysis of a hydrosol of shale.

Si—Al ASSOCIATION IN ORDERED PLAGIOCLASES

George W. DeVore
Dept. of Geology, University of Chicago, Chicago, Ill.

The possibility of several ordered compositions in the plagioclase series accounts for the absence of a continuous solid-solution series for the low-temperature forms. From bond-energy considerations, the three types of lowest energy (ordered) Si—Al associations are represented by: anorthite in which all the Si's share four anions with Al; ordered An 33.3% in which all Si's share two anions with Al; and ordered albite in which the Si's share one and two anions with Al. The Al distributions which result in these Si—Al associations produce a lower energy for the composition than any other distribution. Consequently, other compositions will tend to adopt these cation associations for their ordered forms. Except for anorthite and An 33.3%, the lowest energy form for each ordered composition contains only two types of Si association with Al. Between An 33.3% and An 90%, the compositions: An 43%, An 50%, An 57%, An 60%, An 66.6%, An 71.4%, An 75%, An 77.7%, An 80%, An 83.3%, An 84.7%, An 85.7%, An 86.7%, An 87.5%, An 88.3%, An 89%, An 89.5%, and An 90% may order so as to contain only Si's which share two and four anions with Al. All intermediate compositions and mixed crystals between albite and An 33.3% must contain at least three types of Si—Al association in the mineral. This results in a higher energy than in a mixture of the bracketing ordered compositions so that ordering should produce unmixing into the bracketing ordered compositions (for example, peristerites). The relationships of these ordered compositions to the problems of exsolution, crystallization, zoning, abundances of certain compositions, and two plagioclase rocks are discussed.

INFLUENCE OF IONIC SUBSTITUTION ON THE STABILITY OF MICAS AND CHLORITES

R. C. DeVries and Rustum Roy
G.E. Research Laboratory and Dept. of Geophysics and Geochemistry, Pennsylvania State University, University Park, Pa.

The influence of substitution in the various structural positions of the micas and chlorites have been studied by synthesizing a series of such phases with controlled compositional changes and determining the equilibrium-decomposition temperature under hydrothermal conditions. The first series of substitutions was in the interlayer ion of the dioctahedral micas from K^+ (muscovite $K \cdot Al_2 \cdot AlSi_4O_{10}(OH)_2$) to Na^+ (paragonite) to Ca^{++} (margarite) to Ba^{++} (unknown). The stability maxima, all given for about 1000 atmospheres—the decomposition products in each case being the appropriate feldspar + corundum + vapor—range from 650°C to 625°C to 575°C respectively; there is no barium compound. The most effective change is the variation from dioctahedral to trioctahedral types. The latter is much more stable; *e.g.*, muscovite—650°C, phlogopite—1050°C; margarite—575°C, seybertite (?)—750°C. Changes in the octahedral ion produced unexpected results: Ni-phlogopite proved to be stable to a few degrees above the Mg-phase, while the substitution of Ga for Al in the tetrahedral layer lowered the stability of phlogopite by about 150°.

In the chlorites the stability maximum does not appear to change from 700°C by more than 20° in going from amesite to penninite, nor by the substitution of Ni for Mg. The chromium chlorites kaemmererite and kotschubeite decompose just below 550°C at comparable pressures. The effect of of substitution on powder x-ray data is illustrated.

PHYSICO-CHEMICAL ASPECTS OF MINERAL DEPOSITION

C. C. DeWitt
Chemical Engineering Department, Michigan State University, East Lansing, Mich.

A theory of mineral deposition is developed which depends solely on the known physical and chemical properties of the atoms composing the minerals. It is postulated that surface atoms of minerals are but partially bound to adjacent atoms. Metallic atoms act as electron sinks; nonmetallic atoms act as electron donors. Elements of groups V_b and VI_b of the Periodic Table are potential electron donors. Such atoms in a mineral surface attract other metallic ions, *e.g.*

$$Cu^{++} + Cu{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{Si}} \rightarrow [Cu{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:}Cu]^{++} + 2\ominus \rightarrow Cu{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{Si}}\ Cu$$

$$Cu^{++} + Fe{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:} \rightarrow [Fe{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:}Cu]^{++} + 2\ominus \rightarrow Fe{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:}Cu$$

For stability the positively charged chalcocite and chalcopyrite ionic molecules require free electrons to neutralize the positive charge. Two general forms of pyrite are known—is there more than one form of chalcopyrite? Pentlandite, $(FeS)_2 \cdot NiS$, could be formed thus:

$$Fe^{++} + Fe{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:} + Ni{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:} \rightarrow [Fe{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:}Ni{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:}Fe]^{++} + 2\ominus \rightarrow Fe{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:}Ni{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{S}}{:}Fe$$

Query: Are there as many as four forms of pentlandite; does crystal habit limit to one form?

Thus pyrrohotite is found associated with small amounts of many metallic atoms. Oxidation of intermediate noble metal sulfides and tellurides leaves the noble metal free.

Ionic adsorption involves the creation of acidic conditions. This evidence should be looked for in or adjacent to every mineral deposit.

The overburden of important metallic sulfide deposits usually contains small amounts of a like metallic silicate. Oxidation, leaching, zeolitic fixation is followed by enriched secondary metallic sulfides in increasing concentration down to the main deposit lying on an impenetrable bedrock or clay. Porous rock or shale allows enriched sulfide and silicate coexistence at the lower levels—*e.g.*, New Mexico, Arizona, Utah porphyry copper deposits.

CORDYLITE RE-EXAMINED

Gabrielle Donnay and J. D. H. Donnay
Geophysical Laboratory, Washington, D. C.; The Johns Hopkins University, Baltimore, Md.

Oftedal's x-ray cell (1931) is incompatible with Flink's morphological axial ratio (1901). Redetermined cell dimensions, $c = 23.08$, $a = 5.100$Å, both $\pm 0.3\%$, give $c/a = 4.525$, checking Flink's $4c/a = 4.5152$. The observed forms are reindexed: 0001, $10\bar{1}0$, $10\bar{1}1$, $10\bar{1}2$, $10\bar{1}4$, $10\bar{1}5$ (only $10\bar{1}3$ is anomalously missing). The dipyramids, combined with Laue groups $6/mmm$ and diffraction aspect $P_{**}c$, rule out all space groups but $P6/mmc$ and $P\bar{6}2c$. With cell content $2BaCe_2F_2(CO_3)_3$, the specific gravity is 4.06 (calculated), against 4.10 (Berman balance). Contrasting with its calcium equivalent parisite and related species synchisite and röntgenite, cordylite has no pseudo-repeat in c but shows a marked pseudo-H-centering in xy projection, accounted for by the practically equal scattering factors of barium and cerium ions. Whereas the parisite minerals show remarkable agreement between observed and calculated refractive indices, observed birefringence of cordylite ($1.577 - 1.764 = -0.187$, Böggild) is inexplicably larger than the predicted value ($1.494 - 1.609 = -0.115$) calculated from reported molar refractivities. The crystal structure consists essentially of alternating hexagonal barium layers and puckered cerium-fluorine layers, interleaved by horizontal carbonate ions. The atomic sites of all elements except oxygen are the same in either space group.

UNUSUAL ALKALI FELDSPAR INTERGROWTH

Gabrielle Donnay and J. D. H. Donnay
Geophysical Laboratory of the Carnegie Institution of Washington, Washington, D.C.; The Johns Hopkins University, Baltimore, Md.

The three-phase intergrowth found on "Spencer N" by Smith and MacKenzie (1954) has been studied by "precession goniometry". Reciprocal cell dimensions are: $a^* = 0.1293$, $b^* = 0.07724$, $c^* = 0.1548$, $\beta^* = 63°49'$ (monoclinic K-phase); $a^* = 0.1377$, $b^* = 0.07829$, $c^* = 0.1556$, $\alpha^* = 86°45'$, $\beta^* = 63°0'$, $\gamma^* = 90°45'$ (Na-phase); and $a^* = 0.1292$, $b^* = 0.07736$, $c^* = 0.1555$, $\alpha^* = 90°26'$, $\beta^* = 63°49'$, $\gamma^* = 92°46'$ (triclinic K-phase), where reciprocal lengths are given in $Å^{-1}$ to $\pm 0.3\%$ and angles to $\pm 10'$. The identification of K and Na phases rests on the value of a^*. The five crystal orientations in the assemblage, plotted on a large stereonet, show that the two albite-twinned crystals of the Na-phase have their twin axis b^* coincident with the bb^* axis of the monoclinic crystal, as in previously known feldspar intergrowths. The two crystals of the triclinic K-phase have no direct or reciprocal row in common, but (within experimental accuracy) are rotated 180° with respect to each other about the monoclinic bb^* axis. The literature contains no example of such an edifice, in which the symmetrical arrangement of two crystals of one phase is governed by a lattice element not of their own but of another phase. Until additional examples are reported, this pseudo-twin should be considered a chance intergrowth.

NEW EVIDENCE RELATING TO THE ORIGIN OF CIRQUES

Wakefield Dort, Jr.
Dept. of Geology, The Pennsylvania State University, University Park, Pa.

Well-developed cirques notch north-facing slopes of the Bitterroot Mountains in the Coeur d'Alene district of Idaho at elevations of approximately 6000 feet. In addition to striations and grooves on the smoothed floors of these cirques, glacially striated bedrock surfaces are present on (1) very narrow divides above the cirque headwalls, (2) crests of spurs between cirques, and (3) small steps on the upper parts of the headwalls proper. Striations in these unusual high-level locations are present only where the cirques are cut into Belt Series quartzites which are more resistant than interbedded argillaceous strata.

The existence of small, essentially horizontal striated surfaces near the top of a cirque headwall cannot be explained by presently accepted hypotheses of cirque origin. Nor does the preservation of

such surfaces agree with the usual description of a relatively small glacier nestling at the base of the headwall of a large cirque.

The evidence suggests that the existence of an underfit glacier in a large cirque is characteristic only of the waning phase of glaciation, and that cirques are brim-full or over-full during waxing and maximum phases. Under such conditions, the headwall would be covered with ice, no bergschrund would exist, and retreat of the headwall would be accomplished by combined plucking and abrasion. The presence of glacially striated surfaces high on the headwall indicates that only slight frost shattering has taken place since the cirque was filled with moving ice and suggests that waning glaciers accomplish very little cirque enlargement.

EOCENE SUBMARINE SLUMPING AND GRADED BEDDING AT COOS BAY, OREGON*

Robert H. Dott, Jr.
Humble Oil and Refining Co., Eugene, Ore.

The Upper Eocene Coaledo formation near Coos Bay, Oregon, has excellent examples of primary sedimentary features, especially in the lower member exposed in sea cliffs. These allow rather accurate environmental and facies reconstructions.

Nonmarine and brackish-water, coal-bearing sediments south of Coos Bay apparently grade northwestward into regularly cross-bedded shoreline sandstones around Agate Beach. Northwest from there to Cape Arago (5 miles) many conspicuous but lenticular shale-pebble and boulder breccias occur with massive sandstones and thin mudstones. These unusual breccias, whose fragments are identical with underlying strata, must have accumulated rapidly after only short transport. Local slump and scour structures and flute casting are present. Gradationally below and laterally northward are very evenly laminated mudstone and partially graded siltstone and sandstone. Load casting, contorted bedding, ripple bedding, ripple marks and small-scale cross-bedding abound. This distinctive sequence is in part a maze of slightly disoriented blocks of varying sizes; one large slump-scoured channel is visible north of Cape Arago.

A fluctuating strand was near Agate Beach. The bottom sloped northwestward into moderately deep water. Periodically submarine slipping of accumulating sediments due to gravity adjustments (possibly triggered by faulting) caused local bending and breaking of stratified blocks of plastic sediments. Lenticular shale-fragment breccias and massive sands formed higher up the slope (southeast) where slumping and transport were most violent, thus breaking blocks into smaller sizes. Most of the finer, laminated sediments were probably deposited by turbidity currents initiated by such slumping.

GEOLOGY OF THE QUAD CREEK AREA, BEARTOOTH MOUNTAINS, MONTANA-WYOMING

F. Donald Eckelmann and Arie Poldervaart
Department of Geology, Columbia University, New York, N. Y.

The Beartooth Mountains consist of a core of granitic gneiss with a migmatite mantle. Detailed mapping of an area astride the gneiss-migmatite boundary indicates the following geologic history.

Deposition of Archean siltstones and marls was followed by folding with north-northeast fold axes and emplacement of ultramafic bodies. This was succeeded by metamorphism and granitization along a northwesterly trend. Later Precambrian norite dike swarms also trend predominantly northwest. Subsequent peneplanation preceded deposition of Paleozoic sediments. Laramide uplift and thrusting also followed a northwest trend and was associated with porphyry intrusives of similar direction. The Laramide structural trend originated in the Archean but was preceded by even more ancient structures directed north-northeast.

Field relations favor a metamorphic origin for the granitic gneisses because of: (1) the continuity

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of the synclinal structure from the migmatite mantle into the granitic gneiss core, (2) the transitional boundary consisting of alternate granitic gneiss and migmatite tongues, each passing gradationally into the other across and along strike, (3) the persistence for limited distances of resistant quartzite and amphibolite horizons in granitic gneiss, and (4) the presence of delicate primary bedding and cross-bedding in quartzite lenses at various levels in the metamorphic sequence. Studies of zircon concentrates in part bridge the gap between the rounded zircons of metasediments and the more nearly euhedral zircons of the granitic gneisses by gradual addition of overgrowth material causing development of new crystal faces.

VOLCANIC SUCCESSION AND POSSIBLE MINERALIZATION IN THE DWYER QUADRANGLE, SOUTHWESTERN NEW MEXICO*

Wolfgang E. Elston
Department of Geology, Texas Technological College, Lubbock, Texas

The Dwyer quadrangle lies southeast of the Santa Rita-Central mining districts. Potentially mineralized pre-Tertiary rocks are largely covered by upper Tertiary volcanics and Tertiary-Quaternary valley fill.

The volcanics, up to 8000 feet thick, belong to two suites separated by an unconformity. The older volcanics grade from andesine-pyroxene andesites to andesine-amphibole latites to quartz-sanidine-oligoclase-biotite rhyolites. The rhyolites consist mainly of tuffs and ignimbrites. There are many erosional intervals within this succession, but none is accompanied by significant chemical changes. The entire older suite has calc-alkaline aspect and possibly developed through fractional crystallization from a granodioritic magma, similar to that of many Laramide intrusives in the region.

The younger volcanics, of calcic aspect, include four basalt and olivine andesite units, a rock on the rhyolite-latite-trachyte boundary, and two minor rhyolites more calcic than those of the older suite. One of the andesites shows evidence of contamination by silicic material. All units of the younger suite are separated by erosional disconformities, each corresponding to a chemical change.

At least three intra-volcanic and one post-volcanic periods of faulting have been recognized. Faults follow the northeast and northwest trends of pre-volcanic (Laramide) faulting and therefore parallel the fractures controlling mineralization in the Santa Rita-Central districts. However, the volcanics are almost everywhere too thick for profitable prospecting.

ORIGIN OF PITCHSTONE

D. O. Emerson and O. F. Tuttle
Division of Earth Sciences, College of Mineral Industries, The Pennsylvania State University, University Park, Pa.

Obsidian from Mono Lake, California, has been subjected to water-vapor pressures up to 60,000 psi at temperatures from 300° to 700°C. Under these conditions water dissolves in the obsidian readily at temperatures and pressures below the solidus, suggesting that the high water content of natural pitchstones may be the result of water entering the obsidian during or subsequent to the initial cooling. Up to 6 per cent water has been dissolved in single pieces of obsidian at 500°C and 20,000 psi, whereas if powdered obsidian is used as the starting material the amount of water may exceed 25 per cent. This discrepancy has not been completely resolved, but it is believed that the high water content obtained when the powder is used as the starting material is in part the result of water being initially trapped between the glass fragments. The final products, whether the initial material is a single piece of obsidian or powdered obsidian, may or may not develop the luster of pitchstone. The exact conditions under which the pitchstone luster is produced have not been fixed, but it has been observed that hydrous glasses containing small amounts (*e.g.* <3%) of water, and hydrous glasses quenched from above the liquidus (regardless of the water content) do not show the pitchstone luster.

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In some runs single fragments of obsidian were removed from the pressure vessels when the water had diffused only part way through the fragment. If the hydrous glass vesiculated, as is often the case, the outer rim of the fragment may have the appearance of perlite while the core retains the characteristic appearance of obsidian.

VARIATIONS IN THE PROPERTIES OF A PARAGNEISS AND ITS CONSTITUENT MINERALS, BIOTITE, GARNET, AND FELDSPAR, AS A FUNCTION OF KIND AND DEGREE OF METAMORPHISM

A. E. J. Engel and Celeste G. Engel
Division of the Geological Sciences, California Institute of Technology, Pasadena, Calif.; U. S. Geological Survey, Pasadena, Calif.

Quartz-mica-feldspar-(in part) garnet paragneiss in the Grenville series, Northwest Adirondacks, trends obliquely across the Grenville Lowlands into the Adirondack igneous massif. During reconstitution and partial migmatization along a 40-mile segment of the gneiss a temperature gradient of about 100°C (500–600°C) seems probable. Degree and pervasiveness of migmatization increase moderately with temperature, but some chemically slightly altered metasediment persists throughout.

The lower temperature end of the segment is a quartz-biotite-oligoclase-muscovite gneiss partly migmatized by quartz-microcline (Na_2O 2.9). At sites of migmatization garnet appears (alm 55.5, pyro 17.9, spess 14.9, andr 6.5, gross 5.2), and biotites increase in Ti, Mg, F, Ba; decrease in Fe, Mn; change from greenish to brown.

As uninjected gneiss is followed in direction of increasing temperature, muscovite disappears, potash feldspar and garnet (as above) appear. Garnet changes consistently (21 analyses) toward alm 62.9, pyro 30.6, gross 3.6, andr 1.6, spess 1.3, with increases in Co, V; decreases in Cu, Sc, Y. Sympathetic changes in biotite (24 analyses) are to deep reddish brown, higher TiO_2 (5.5), MgO (12.0–13.0), F (0.7), Ba, Cr, V, but lower FeO (14.0–15.0), Fe_2O_3 (0.8–1.5), Mn, Sc. Changes in optical constants and structure of biotite are less consistent. The polymorphs 1M, 2M, 3T (assists from Chodos, Levinson, Yoder) occur together, widely.

With increasing temperature the least-injected gneiss appears to undergo metamorphic differentiation, also gains Ca, P, Ti, possibly Cu, Al, Mg, Na, V; but loses Ba, K, probably Mn, Si, Zn. All migmatization involves major additions or widespread redistribution of K, lesser Al, Na, large losses of Ca, Fe, Mg (decreased biotite, garnet, plagioclase).

STREAM TERRACES ALONG MICHIGAN RIVER, NORTH PARK, COLORADO

Donald F. Eschman
Department of Geology, University of Michigan, Ann Arbor, Mich.

Six terraces of Pleistocene age are present along the valley of Michigan River, a headwater tributary of the North Platte, in North Park, Colorado. The terraces range in height above the modern stream from 20 to 210 feet. Several miles from the mountain front all the terraces are cut terraces, but the two lowest terraces studied become fill terraces as the mountain front is approached. Both fill terraces terminate at glacial moraines of Wisconsin age. The stream profiles reconstructed from the terraces all closely parallel the profile of the modern stream.

The evidence suggests at least six periods of lateral planation, during each of which the stream had a grade similar to that of the present Michigan River. Separating these periods of strath development were periods during which downcutting was predominant. Such a complex series of events can be explained only by climatic changes. The fact that the terraces are all of Pleistocene age and that the two lowest terraces can be definitely correlated with glacial advances in the mountains support this hypothesis. The correlation of the two lower terraces with glacial advances in the mountains sheds light on the types of climatic change necessary to bring about the changes of stream regime.

Several questions concerning the assumed interrelationship of load, discharge, and grade of a stream are brought to light by this analysis.

EXPERIMENTAL DETERMINATION OF THE DISTRIBUTION FACTOR OF TRACE ELEMENTS

H. P. Eugster
Geophysical Laboratory, 2801 Upton St., N. W., Washington, D. C.

The distribution factor F for the cesium-potassium equilibrium in the system $(K,Cs)AlSi_3O_8$—H_2O (sanidine-water) has been determined at different temperatures and pressures in the subsolidus region. Factor F is defined as the ratio of Cs/K in sanidine to Cs/K in fluid phase. For low concentrations of cesium (< 1000 ppm) and constant temperatures and pressures the Cs/K ratio in sanidine is directly proportional to the Cs/K ratio in the fluid phase from which sanidine grows. Factor F is strongly temperature dependent: $F_{(800°)} = 1.20$; $F_{(700°)} = 0.96$; $F_{(600°)} = 0.70$; $F_{(500°)} = 0.48$. The pressure influence between 1000 and 2000 bars water pressure was found to be smaller than the experimental error (+5%).

The Cs/K ratio of a given feldspar will depend on the original Cs/K ratio of the hydrous liquid or fluid from which it crystallized, the temperature of crystallization, and the extent of fractionation between liquid and solids. Complete fractionation between liquid and crystals in a system with fixed volume will lead to a sharp increase of the Cs/K ratio in the feldspars of the late stage for temperatures at which F is substantially smaller than 1.

If no fractionation takes place the Cs/K ratio of the feldspars in the crystallized body will be uniform, independent of the temperature and equal to the Cs/K ratio of the original liquid.

Solutions which form by interaction of volatiles with the country rock will leach cesium preferentially at temperatures below 700°C and will therefore show a larger Cs/K ratio than the feldspars of the country rock. This increase is solely dependent on the temperature at which solution occurs. Fractional crystallization of such solutions can enhance this enrichment for feldspars crystallizing at a late stage.

FOUNDATION ENGINEERING PROBLEMS IN NEW ORLEANS AREA

J. Bres Eustis
Eustis Engineering Company, 3635 Airline Highway, New Orleans, La.

Substrata in the Greater New Orleans area consist of two principal geologic formations; a Recent deposit of soft peats, organic clays, and clays with layers and lenses of fine sands, and a late Pleistocene deposit of stiff to medium stiff clays and dense sands.

The Recent deposits extend from the ground surface to depths ranging from 45 to 110 feet. The Pleistocene is usually oxidized for 5–25 feet below the top of the bed and is readily recognized by its distinct tan and gray color.

Basic problems confronting designers, as in other municipalities, are determination of either the allowable soil-bearing value or safe-pile load capacity. The major problem in New Orleans however is how to eliminate, or at least minimize, the settlement of structures caused by consolidation of clay strata located principally in the Recent formation.

Support of structures on piles is commonplace. Major structures are usually founded on either deep piles to Pleistocene or on piles into dense sand stratum in Recent material when present. Preloading of some warehouse areas has been used with success thereby eliminating pile foundations for floors. Spread footings are used satisfactorily for small buildings within the areas of natural levee deposits adjacent to the Mississippi River. Use of footings in areas distant from the river results in most cases in settlement and cracking in varying amounts depending on depth to, and thickness of, underlying peats and organic clays. More recently, slab foundations on compacted fill have proven successful for residences.

VANADIUM MINERAL ALTERATION SEQUENCES IN RELATION TO CRYSTAL CHEMISTRY AND THERMODYNAMICS

Howard T. Evans, Jr.
U. S. Geological Survey, Washington, D. C.

All available thermodynamic and chemical data have been drawn upon to compile a phase diagram in the oxidation potential-pH field for vanadium in aqueous solution. Regions in which trivalent, tetravalent, and pentavalent states of vanadium are stable lie within range of the natural conditions in the Colorado Plateau area. The chemical properties and mineral associations of the various vanadium minerals allow each species to be associated with specific stability regions on the phase diagram and permit tracing of alteration sequences. The chief primary vanadium ore mineral is montroseite, which forms the focus of the alteration phenomena. Montroseite is converted by weathering to paramontroseite, corvusite, pascoite, and hewettite, under acid conditions. Under more alkaline conditions, paramontroseite may be converted to two new minerals, $VO(OH)_2$ and $CaV_6O_9 \cdot 5H_2O$, and then successively to melanovanadite and rossite.

GEOPHYSICAL INVESTIGATIONS IN THE EASTERN CARIBBEAN—TRINIDAD SHELF, TOBAGO TROUGH, BARBADOS RIDGE, ATLANTIC OCEAN

J. I. Ewing, C. B. Officer, H. R. Johnson, and R. S. Edwards
Lamont Geological Observatory, Palisades, N. Y.; Rice Institute and Woods Hole Oceanographic Institution, Woods Hole, Mass.; Woods Hole Oceanographic Institution, Woods Hole, Mass.; Woods Hole Oceanographic Institution, Woods Hole, Mass.

Twenty one seismic-refraction stations located in the southeastern Caribbean show the basic structural features of the lower part of the Windward Island Arc, the Tobago Trough, The Barbados Ridge, and the area east of Barbados extending out to the deep ocean (2800 fathoms). The entire area is underlain by a basaltic basement and appears to be of oceanic origin. The basement is at a minimum depth under the Windward Islands and reaches a maximum depth under the Barbados Ridge where sediments and volcanics are at least 6–8 km thick. This evidence indicates that the Barbados Ridge may formerly have been a trough in which large quantities of sediments were deposited and subsequently uplifted to the present configuration. Because of the great thickness of the overlying sediments, penetration to the discontinuity under the Barbados Ridge was not possible with the available explosives. However, the two easternmost profiles show the discontinuity at a depth of about 12 km below sea level with the interface apparently bending down beneath the ridge.

GEOTECTONIC SIGNIFICANCE OF THE CONTINENTAL SHELVES

Rhodes W. Fairbridge
Department of Geology, Columbia University, New York, N. Y.

A continental shelf is viewed essentially as a geomorphic concept, its limits ranging from zero up to great widths and depths, even to 500 miles and 500 fathoms. In perspective of geological time, it ranges from the inner edge of the coastal plain to the outer shelf edge, between which periodically oscillates the littoral belt, conditioned by eustatic and tectonic events.

In the past, the shelf has been variously regarded as a sedimentary wedge, a wave-bevelled terrace, or as a "quarry and tip" or combination feature. Field studies in Australia, with analogies drawn from North America, Europe, and the Middle East, suggest that not one theory, but all, may be applied in different areas. The hypsographic curve indicates a bevel and wedge combination, an average for the Earth, but geotectonic history of areas varies the effect: long stability increases the bevel, instability increases the size of the sedimentary wedge.

Shelves represent the site of most contemporary sedimentation, and more than 90 per cent of sediments in the geologic column are neritic. Filling both para- and orthogeosynclines, which may possess bathyal or abyssal depths, sediments initially deposited on the shelf are transported into the deeps by wave current, density flow, gravity slump, and ultimately by major tectonic slide (often so-called nappe overthrusts). Tide-gauge work indicates that almost all sedimentary shelves are subsiding today and most rocky shelves are stable or rising. With alternation in geologic periods between thalassocratic and epeirocratic episodes (eustatic controls), there will be an oscillation of the axis of subsidence from the inner edge of the shelf to the slope and back.

CRYSTALLOGRAPHY OF SYNTHETIC $YTaO_4$ AND FUSED FERGUSONITE

R. B. Ferguson
University of Manitoba, Winnipeg, Canada

Attempts to find a possible structure for synthetic $YTaO_4$ using powder data indexed on the primitive tetragonal cell of Barth (1926) proved fruitless, and experiments were carried out to produce single crystals. Fusion of the appropriate amounts of Y_2O_3 and Ta_2O_5 in the cratered graphite electrode of an arc lamp eventually yielded minute single crystals, commonly twinned polysynthetically. One fragment finally permitted x-ray orientation about a rational axis, and a series of oscillation and Weissenberg photographs were taken about this axis. This crystal, seemingly single under the microscope, proved to be a parallel growth along the rotation axis of two individuals, but the two reciprocal nets were easily distinguished. The photographs show that $YTaO_4$ is not tetragonal but monoclinic with probable space group I2/a; $a = 5.34$, $b = 10.94$, $c = 5.07$ Å, $\beta = 95.3°$; $Z = 4$; ρ calc. $= 7.47$. Our rotatio axis is b. The tetragonal cell is unreal with $V_{tet.} = 2\frac{1}{3} V_{mon.}$, and apparently with tetragonal [100], [010], and [001] quasi-equivalent to monoclinic $[\frac{1}{2}\frac{1}{2}1]$, $[\bar{\frac{1}{2}}\frac{1}{2}1]$, and $[20\bar{1}]$. An analysis of the structure is to be attempted using the single-crystal data.

Several metamict fergusonites gave, after fusion in the arc-lamp electrode, powder photographs which confirmed Barth's observation that fused fergusonite is isostructural with synthetic $YTaO_4$ with closely similar cell dimensions.

SLUMPS AND MUD FLOWS IN ROCKS OF PENNSYLVANIAN AGE IN THE APPALACHIAN PLATEAU

John C. Ferm and John W. Huddle
U. S. Geological Survey, Lexington, Kentucky

Deformed rocks interpreted as the result of penecontemporaneous slump and mud flow are common in rocks of Pennsylvanian age in the Appalachian Plateau. Reconnaissance in Pennsylvania, Ohio, West Virginia, Kentucky, and Tennessee located many examples ranging in age from oldest to youngest Pennsylvanian. In individual areas of detailed study in Pennsylvania and Kentucky, deformed rocks occur in as many as 50% or as few as 15% of the exposures examined. Examples are much more numerous and occur in a larger area than previously reported.

The observed zones of deformed rocks range in thickness from 1 inch to 70 feet and in horizontal extent from a few feet to 4½ miles. They are limited at the top and bottom by undisturbed strata. Features seen in deformed zones include normal and reverse faults, belts of complex shearing, folds, ellipsoidal masses of rolled up sediments, transported blocks, and massive beds with poor grain orientation. These features represent rigid, plastic, and fluid behavior of sediments under stress. On the basis of these stress reactions, two general types of deformed strata, slump and mud flow, are distinguished. Slumps include strata which deformed rigidly by simple or complex faulting and plastically by folding. Mud flows include strata which deformed mainly as fluids and partly as plastics.

VANADIUM AND URANIUM IN ROCKS AND ORE DEPOSITS*

R. P. Fischer

U. S. Geological Survey, P. O. Box 360, Grand Junction, Colo.

Trace amounts of vanadium and uranium are common in both igneous and sedimentary rocks. Vanadium is more abundant in basic igneous rocks, uranium in the acidic ones. Both metals tend to concentrate abnormally in sedimentary rocks containing organic material.

With few exceptions, vanadium does not tend to concentrate in hypogene ore deposits. Its average concentration in 775 samples of ores and mill products is less than 100 ppm, which is less than the reported average content in igneous rocks and shales. It appears in similarly low concentrations in hot-spring precipitates and solutions. Among hypogene vein deposits containing some vanadium, two types that may have escaped specific notice previously are those in which vanadium is associated with titanium and with tellurium.

Apparently vanadium is equally sparse in hypogene deposits that contain uranium ore. Vanadium is not mentioned in published geologic reports on most productive uranium-bearing veins, perhaps because its content is too low to form easily recognized vanadium-bearing minerals. Available spectrographic determinations of samples of uranium-bearing veins show an average vanadium content no greater than the average concentration in the samples of ores and mill products.

Thus vanadium apparently does not tend to concentrate in the normal hypogene environment, and specifically it does not appear to concentrate in most hypogene veins containing uranium ore. If this is true, unusual processes and conditions might be required to explain a hypogene source of vanadium and uranium in deposits containing commercial concentrations of both metals.

SODA FE-MN PEGMATITE PHOSPHATES

D. Jerome Fisher

Rosenwald Hall, University of Chicago, Chicago, Ill.

This paper describes the results obtained from x-ray and thermal studies on single crystals and powders of a number of soda Fe-Mn phosphates. The Fe″ compound ferrodickinsonite, heated in a vacuum, inverts irreversibly to ferrofillowite at 850°C. If heated in air for a day it oxidizes to alluaudite near 500°C. The diffraction pattern from fillowite heated in air for 2 days at 885°C. is rather close to that from alluaudite.

Crystallographic Data

	a	*b*	*c*	beta	Space Group
Fillowite	15.25	—	43.32	—	148—R $\bar{3}$
Dickinsonite	24.89	10.11	16.68	105°41′	15—A $2_1/n$
Alluaudite	11.99	12.44	6.38	114°20′	15—C 2/c

TIME SPAN OF THE THERESA AND POTSDAM FORMATIONS IN THE REGION PERIPHERAL TO THE ADIRONDACK MOUNTAINS, NEW YORK†

Donald W. Fisher

N. Y. State Geological Survey, Albany, N. Y.

Paleontologic evidence from the Paleozoic rocks rimming the Adirondacks indicates three successive time-transgressive stable shelf phases of sedimentation: (1) quartzose sand (Potsdam); (2)

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mixed quartz sand and dolomite (Theresa); (3) multiple carbonate phase comprising (a) lower infra-lagoonal Little Falls, (b) intermediate *Cryptozoon*-rich biostromal Hoyt containing a commensal trilobite fauna, and (c) upper neritic cephalopod-rich Tribes Hill.

A Lower Ordovician fauna (cystid plates, *Ecculiomphalus* sp., *Ophileta hunterensis*, *Ozarkina* sp., *Sinuopea* sp.) discovered in the Theresa type area demonstrates the synchroneity of the clastic type Theresa and the established Lower Ordovician (Gasconadian) Tribes Hill limestone of the Mohawk Valley. *Lingulepis acuminata*, a facies fossil, is unreliable as an Upper Cambrian index. The restricted Heuvelton and Bucks Bridge units are regarded as members of the Theresa. Southeast of the Adirondacks, the Theresa contains the diagnostic lower Franconian trilobites, *Berkeia*, *Camaraspis*, and *Elvinia*. Southern Champlain Valley Theresa is post-middle Franconian and pre-latest Trempealeauan.

The Potsdam, unfossiliferous at the type locality and westward, is Upper Franconian (*Prosaukia*, *Ptychaspis*) in the Chateaugay section, where the Theresa is Trempealeauan and/or Gasconadian. Northern Champlain Valley Potsdam contains lower Dresbachian (*Climachtichnites*, *Protichnites*), middle Dresbachian (*Lonchocephalus*), and upper Franconian (*Ptychaspis*) fossils, whereas in the southern Champlain Valley middle Dresbachian (*Komaspidella*, *Lonchocephalus*), lower Franconian (*Berkeia*, *Camaraspis*, *Elvinia*), and middle Franconian (*Conaspis*) fossils occur. Along the southern Adirondack border the Potsdam is traceable into lower Franconian Little Falls dolomite.

Potsdam deposition began in the northern Champlain Valley in early Dresbachian reaching the St. Lawrence Valley in latest Cambrian or earliest Ordovician. Theresa deposition began in the early Franconian along the southeastern Adirondack periphery and reached the St. Lawrence Valley in early Ordovician.

GEOLOGICAL SETTING OF NEW ORLEANS

Harold N. Fisk
Humble Oil and Refining Company, P. O. Box 2180, Houston, Texas

New Orleans began in 1717 as a settlement along the natural levee flanking the eastern bank of the Mississippi River and spread across lowland swamps and marshes to the banks of Lake Pontchartrain. The sequence of marine and deltaic deposits beneath the levee and lowland is known from many borings necessitated by the search for structural foundations. These deposits have been interpreted as to environment of deposition, and their age has been determined from radiocarbon analyses. At shallow depth they bury deeply weathered late Pleistocene strata forming the divide between the late Wisconsin entrenched valley systems of the Amite and Mississippi rivers that were eroded approximately 30,000 years ago. The marine sands and clays were all deposited less than 10,000 years ago, late in the transgression of Gulf waters that occurred when sea level rose in response to melting of the late Wisconsin glaciers; when the sea reached its present level, approximately 5000 years ago, the Gulf shore lay inland from New Orleans. The regional dip of the marine beds provides a measure of Gulfward subsidence. The near-surface deltaic deposits are characterized by prodelta brackish-water silts and clays and by peat beds; they mark epochs in local progradation of the Mississippi deltaic plain and indicate alternate enlargement and deterioration of Lake Pontchartrain. Creation of existing conditions began less than 1000 years ago when the Mississippi established its present course. Continuing compaction of swamp deposits and regional subsidence have brought original swamp lowlands within the city beneath sea level.

WISCONSIN STRATIGRAPHY AND RADIOCARBON DATES AT SEARLES LAKE, CALIFORNIA

Richard Foster Flint and W. A. Gale
Yale University, New Haven, Connecticut; American Potash and Chemical Corporation, Whittier, Calif.

Subsurface deposits of ancient Searles Lake, California, includes conspicuous layers of evaporites and bodies of laminated clay and silt containing organic matter. The general character of the se-

quence, and radiocarbon dates from critical horizons, suggests that a Wisconsin pluvial unit and an underlying interpluvial unit are represented. The evidence supports the general correlation of glacial times with pluvial times. It suggests (by analogy only) that the Stansbury strand line of Lake Bonneville might represent a Wisconsin pluvial maximum or a time shortly thereafter.

BLISS AND EL PASO SUCCESSIONS IN NEW MEXICO

Rousseau H. Flower
New Mexico Bureau of Mines, Socorro, N. M.

The Bliss sandstone contains a lower unit of Franconian age in central New Mexico, absent in western Texas. Trempealeauan beds are missing. The upper Bliss is equivalent to earliest Canadian and Tremadoc, and is probably not separated from the lower El Paso by any significant depositional break. The El Paso is divided into (1) Gasconade beds with *Symphysurina*, (2) a *Kainella-Leiostegium* zone, younger than the *Paraplethopeltis* beds marking the top of the Gasconade in most eastern sections. Middle Canadian beds contain (3) a first endoceroid zone and (4) a first piloceroid zone; both contain faunas more advanced and possibly younger than the *Lecanospira* beds of the east. A oolite bed (5) contains a fauna as yet without apparent correlates. Upper Canadian begins with (6) a *Mcqueenoceras* zone and (7) a second piloceroid zone, Jefferson City equivalents. Succeeding beds are not as yet differentiated into Cotter and Powell equivalents. In the Franklin Mountains a depositional break separates Smithville-Ft. Cassin equivalents from underlying beds, and is capped by very late Canadian. Correlation is possible with the Garden City trilobite zones of Utah, as well as with eastern sections. Faunal elements are discussed of the various zones. The faunas indicate original continuity between the El Paso seas and those in which the Garden City of Utah and the Manitou of Colorado were deposited. Their present separation is due to later erosion, which has also removed much of the upper part of the Canadian in most sections in New Mexico.

GENERAL EDUCATION IN THE HUMANITIES: AN ANTIDOTE FOR DANGEROUS SPECIALIZATION IN THE GEOLOGIC CURRICULUM

Richard M. Foose
Franklin and Marshall College, Lancaster, Pa.

Many undergraduate students take a large number of courses in geology at the expense of a well-balanced curriculum including courses in the humanities, social sciences, and basic sciences. Such undergraduate specialization may result in the training of a first-rate technician but less often in a first-rate scientist and citizen. A broad and general education in the humanities is highly beneficial to the student by helping him to write and speak more effectively, to gain a fuller appreciation of the relationship between the arts and sciences, and to understand better the role of his profession in modern society.

TERTIARY REEFS IN SOUTH LOUISIANA

McLain J. Forman
c/o Gordon Atwater, Consulting Geologist, Whitney Building, New Orleans, La.

Detailed stratigraphic and sedimentary studies reveal the presence of coral reefs in the subsurface Tertiary strata of south Louisiana. These reefs are locally developed around certain piercement-type salt-dome structures, particularly in the strata deposited in the transgressive sea of *Heterostegina* (middle Tertiary) time.

Interpretation of subsurface structural, isopachous, and lithofacies maps of the *Heterostegina* zone strata in the vicinity of the Anse la Butte salt dome, Lafayette and St. Martin parishes, Loui-

siana, reveals the presence of one of these reefs. This fossil reef is interpreted as having been formed on a raised area, where intrusion of the salt plug had uplifted the sea floor prior to *Heterostegina* time. Favorable ecological conditions over the uplifted area (shallow, warm and relatively clear water) permitted the local establishment of a reef biota. Subsequent growth of this biota and the distribution of calcareous debris derived from it resulted in the formation of a localized reef facies. This reef facies contrasts with the surrounding terrigenous (sandy shale) facies.

Comparison of this fossil reef with recent reefs found on topographic domes in the Gulf of Mexico off the Texas and Louisiana coasts reveals striking similarities. The Anse la Butte reef is interpreted as a fossil counterpart of these recent reefs.

EXPLORATION FOR THE CUBATAO UNDERGROUND POWERHOUSE AND PRESSURE SHAFT, BRAZIL

Portland P. Fox
Route 2, Box 225, Cleveland, Tenn.

This underground powerhouse, the third to be completed in Brazil since 1953, consists of six units of 65,000 KVA each operating from a single pressure shaft under a head of 715 meters. It is located in the escarpment of the Serra do Mar 16 km northwest of Santos, Brazil.

Although a detailed geologic study of the region revealed no serious bedrock defects that would cause construction problems in the Archean gneisses and Algonquin quartzites, marbles, and phyllites, it was deemed advisable to make an extensive investigation of the subsurface conditions by a number of diamond-core drill holes along the pressure shaft and in the proposed locations of the powerhouse. Thirty-three holes, totalling 3352.95 m, were drilled. Five of the holes exceeded 200 m in depth, and one attained a depth of 290 m. Not all the holes penetrated to the full depth of the pressure shaft if there were no serious bedrock defects encountered in the first 50 m. This saved considerable drilling. A core-hole spacing of 100 m center proved adequate because of favorable geologic conditions. The deeper holes deviated as much as 25° from the vertical at the bottom. Ax-sized holes proved adequate for the hard rocks encountered and saved considerable cost over the larger sizes.

The excavation was completed for the powerhouse and pressure shaft without the use of any supports, but some quartzite in the powerhouse area was quite blocky, and roof bolts were used extensively.

LOCATION OF UNDERGROUND CAVITIES

Albert J. Frank, Otto W. Nuttli, and Carl Kisslinger
St. Louis University, 3621 Olive Street, St. Louis, Mo.

The problem of locating and surveying old mine workings or cavities resulting from such workings was solved by using electrical resistivity. This method was chosen in preference to other geophysical methods because it allows the depth of exploration to be controlled and because any underground cavities could be expected to have a marked contrast in electrical resistivity with the surrounding rock. Actual data revealed the cavities are represented by high resistivity. The material that had been mined was the Pennsylvanian fireclay of a Wellerian cyclothem. The problem was somewhat complicated by the existence of limestone in an overlying cyclothem. As the limestone is highly resistive two effects were encountered with the deep effect of the cavities superimposed on the shallower effect of the limestone. The interpretations were proven by drilling and the results indicated once again the feasibility of using electrical methods in locating underground cavities.

DEUTERIUM CONTENT OF WATER IN TEKTITES

Irving Friedman
U. S. Geological Survey, Washington, D. C.

The water contained in specimens of tektite from French Indochina, the Philippines, and Australia was extracted by vacuum fusion of the sample contained in a platinum crucible heated to 1450°C. The extracted water was completely reduced by reaction with hot uranium metal. A specially constructed mass spectrometer was used to determine the hydrogen-deuterium ratio of the hydrogen gas.

Published water analyses (H_2O+) of tektites ranged from 0.01 to 0.6 per cent. The present analyses give results ranging from 0.002 to 0.008 $\pm$ 0.001 per cent. The deuterium-hydrogen ratio of these waters is approximately the same as that of water dissolved in terrestrial obsidian, but the water from these tektites contains about 15 per cent less deuterium than average ocean water.

It is not possible to separate the tektites examined from terrestrial obsidian solely on the basis of deuterium content. However, the low water content contrasts with the higher water content of obsidians (0.08 to 0.5 per cent) analyzed by the same method.

CRYSTAL STRUCTURE OF STROMEYERITE, AgCuS: A POSSIBLE DEFECT STRUCTURE

Alfred J. Frueh, Jr.
Department of Geology, University of Chicago, Chicago, Ill.

Stromeyerite, below 93°C, forms orthorhombic crystals having space-group symmetry Cmcm, with $a = 4.06$ Å; $b = 6.66$ Å; $c = 7.99$ Å. The unit cell contains $Ag_4Cu_4S_4$, with each element occupying four-fold special positions. The Ag is at 000, 00½, ½ ½0, and ½ ½ ½. The Cu and S atoms are at 0 y ¼, 0 $\bar{y}$ ¾, ½ ½ + y ¼, and ½ ½ − y ¾, where the y parameter for Cu is 0.46 and for S is 0.80.

The volumes of the principal Brillouin zones of stromeyerite have been computed. The assumed electron-to-atom ratio will not exactly fill any of the principal zones. Consequently, a small portion of the electrons must be at a higher energy level separated from the others by an energy gap. A defect structure with up to 0.1 of the Ag atoms missing at random is proposed as a possible lower-energy structure. This suggestion is in agreement with the experimental data found in the literature on the preparation of synthetic stromeyerite.

MIDDLE DEVONIAN STROMATOPOROIDEA FROM INDIANA

J. J. Galloway and J. St. Jean, Jr.
Indiana University, Bloomington, Ind.; Trinity College, Hartford, Conn.

Splendidly preserved stromatoporoids from the Logansport limestone of Hamilton age and Little Rock Creek limestone of Tully age in north-central Indiana and from the lower Jeffersonville limestone of Onondaga age throughout southern Indiana are exceptionally good index fossils. The families Clathrodictyidae, Actinostromatidae, Stromatoporidae, and Idiostromatidae, four of the five stromatoporoid families, are well represented, making the faunas ideal for systematic and stratigraphic studies.

The Jeffersonville fauna contains 27 species, of which 17 are new, and correlates with faunas from the Columbus limestone of Ohio and the Onondaga limestone of Ontario. The Logansport fauna contains 28 species, of which 21 are new, and correlates best with Frasnian and Faminian faunas from the Dinant Basin, Belgium. The Little Rock Creek fauna, which correlates with our unpublished material from the Potter Farm formation of Upper Hamilton age in Michigan, contains 8 species,

7 of them new. *Stylodictyon microtuberculatum* (Riabinin) is identical with the type from the Main Devonian Field near Leningrad, Russia. *Amphipora ramosa* (Phillips), from the Jeffersonville limestone, is the most widespread of the Indiana species, occurring in the Middle Devonian of Montana, Mid-Western North America, England, Europe, the Urals, Yunan, China, and Western Australia.

The Indiana faunas are significant because they are diversified, they can be correlated over large areas, they occur under many ecological conditions as in bioherms, biostromes, and inter-reef facies, and are associated on the surface with the stratigraphic and lithologic units which are Devonian oil reservoirs in the subsurface in southern and western Indiana.

STRUCTURE AND CLASSIFICATION OF THE GENERA OF THE STROMATOPOROIDEA

J. J. Galloway and J. St. Jean, Jr.
Indiana University, Bloomington, Indiana

Stromatoporoidea are laminated, organic bodies occurring in marine deposits of Ordovician, Silurian, and Devonian age. They frequently occur in large beds and make organic reefs or bioherms. They occur in profusion in North America, Europe, and Asia, commonly in Australia, and Morocco, but are unreported from South America.

Stromatoporoidea are considered, to be an extinct Order of Hydrozoa, the ancestors of the Upper Paleozoic Order Sphaeractinoidea, and in turn related to the modern Order Hydroidea, especially the hydractinoids and milleporoids.

The stromatoporoids consist either of cystose plates, cysts and pillars, or of laminae and pillars. They are here classified into five families, a modification of H. A. Nicholson's classification of 1886. We include every genus ever proposed for what we consider to be real Stromatoporoidea, and recognized as valid only 34 genera of the 73 or more which have been proposed.

In the first part, the structure, its systematic significance, the geographic and stratigraphic occurrence, the astogeny, ancestry and phylogeny are discussed, as well as the systematic position, ecology, and fossilization, a glossary of terms, and a complete bibliography.

The larger, second part of the work consists of a precise description of each valid genus, with occurrences and distinctions, keys of the families and genera, with typical figures of the genera, and figures of all the types, with supplementary figures. One new genus is proposed.

APPLICATION OF CATION-EXCHANGE REACTIONS TO THE PUTNAM BEIDELLITE

R. M. Garrels and C. L. Christ
U. S. Geological Survey, Washington, D. C.

The titration curve for the reaction of the H-form of Putnam beidellite with KOH can be predicted on the assumption that the beidellite consists of two distinct substrates, and that the law of mass action applies to the cation exchange. For the reactions

$$HC + K^+ \rightarrow KC + H^+$$
$$HE + K^+ \rightarrow KE + H^+$$

where C represents the one substrate, and E the second, the equilibrium constants are respectively $10^{-2.5}$ and $10^{-6.7}$. For the reactions

$$HC + E^- \rightarrow HE + C^-$$
$$KC + E^- \rightarrow KE + C^-$$

the constants are $10^{4.2}$ and 10^{0}. Therefore K^+ shows little difference in bonding energy between the two substrates, whereas H^+ is much more firmly bonded to one than to the other. Use of the concept

of two substrates may permit semiquantitative calculation of exchange relations for various ions in a variety of clays. Preliminary work shows that hydrous micas, as well as other montmorillonites, are amenable to similar calculations.

SOME ASPECTS OF THE CRYSTAL CHEMISTRY OF THE OXIDATION OF THE COLORADO PLATEAU URANIUM ORES

R. M. Garrels and C. L. Christ
U. S. Geological Survey, Washington, D. C.

Uranium occurs as U^{+6} and U^{+4} in minerals of the Colorado Plateau ores. The number of species containing U^{+6} is large, but there appear to be only two primary minerals: uraninite, an oxide, and coffinite, a hydroxy-silicate. These oxidize to yield U^{+6} before reacting significantly with other mineral constitutents. Crystal-structure analysis has shown that U^{+6} invariably occurs as uranyl ion, UO_2^{+2}. Uranyl ion may form complex carbonate or sulfate ions with resulting soluble compounds, but only in the absence of pentavalent vanadium, arsenic, or phosphorus. In the presence of these elements in the +5 state, the uranium ion is fixed in insoluble layer compounds formed by union of uranyl ion with orthovanadate, orthophosphate, or orthoarsenate. Under favorable conditions UO_2^{+2} may react to form the relatively insoluble rutherfordine, UO_2CO_3, or hydrated uranyl hydroxides. These are rarely found on the Colorado Plateau as opposed to their excellent development in other areas, a condition which is apparently related to the semiarid climate of the Plateau. Uranium may also be fixed as uranyl silicate, but little is known about minerals of this kind. In the present study emphasis has been placed on a detailing of the chemical and crystal structural changes which occur in the oxidation paragenetic sequence.

WHAT IS A GRAVITY ANOMALY?

Richard A. Geyer and Frederick E. Romberg
Geophysical Service Inc., 204 Baker Bldg., 3601 So. Sandman St., Houston, Texas

The term "gravity anomaly" does not have the same connotations to all earth scientists, and similarly all gravity anomalies do not have the same geologic significance. The purpose of this paper is to analyze the fundamental physical and geologic factors which must be considered in the evaluation of gravity anomalies from the standpoint of the regional geologist and the economic geologist, as well as the geodesist and geophysicist.

This analysis includes a discussion of the limitations as well as the potentialities of higher-order derivatives for interpreting the structural and stratigraphic significance of gravity surveys.

In developing these criteria examples based on regional and local field studies are presented. Emphasis is placed on certain areas in Texas in which the interrelationship between pure and applied geological and geophysical studies can be demonstrated in some detail. These areas include portions of Travis, Blanco, and Gillespie counties.

INVESTIGATIONS IN THE SYSTEM CaO-MnO-CO_2

Julian R. Goldsmith and Donald L. Graf
Department of Geology, The University of Chicago, Chicago, Ill.; Illinois State Geological Survey, Urbana, Ill.

A complete series of solid solutions between $CaCO_3$ and $MnCO_3$ (manganoan calcites and calcian rhodochrosites) exists above 500°C, at CO_2 pressures sufficient to prevent decomposition. At 450°C there is a solubility gap in the region of the calcium-rich rhodochrosites. At 400°C and below, experimentation is hampered by very slow reaction rates, both in hydrothermal runs and in dry runs using Li_2CO_3 as a flux.

The dolomitelike ordered compound $CaMn(CO_3)_2$, kutnahorite, does not appear to have been produced, although a solid solution of this composition is readily formed. Calculation of the x-ray reflection intensities, based on a dolomite model with cell constants of the $CaMn(CO_3)_2$ composition, shows that at least two superstructure reflections should be clearly visible. No superstructure reflections are observed in x-ray patterns of the synthetic products, and the observed intensities of these reflections for several natural kutnahorites are far below the calculated values.

The equilibrium thermal decomposition curve for the reaction $MnCO_3 \rightarrow MnO + CO_2$ has been determined in the range from 1 to 2000 atmospheres CO_2 pressure. The plot of these data as log P_{CO_2} vs. $1/T°_K$ is a straight line except for a slight curvature above approximately 1200 atmospheres. The curve passes through 370°C at 1 atmosphere CO_2 pressure, 685°C at 680 atmospheres, and 780°C at 2040 atmospheres. At temperatures below approximately 650°C, hausmannite (Mn_3O_4) and iron-free bixbyite (Mn_2O_3) form unless the partial pressure of oxygen is kept very low.

ALASKAN CARBONIFEROUS GONIATITES

Mackenzie Gordon, Jr.
U. S. Geological Survey, Washington, D. C.

Cephalopods of Mississippian age occur in the rocks of northern and eastern Alaska. They include goniatites similar to those in zones in northwest Europe, particularly the British Isles.

In the western part of the Brooks Range, shale and limestone at two localities have yielded *Münsteroceras* probably of late Tournaisian (early Mississippian) age. At two other localities, beds referred to the lower part of the Lisburne group contain *Ammonellipsites* at a stage of development that suggests very late Tournaisian or early Viséan age.

In the central Brooks Range most of the goniatites occur in a dark-gray shale and chert unit in the upper part of the Lisburne group. Included within rather narrow stratigraphic limits are *Beyrichoceras*, *Goniatites*, *Sudeticeras*, *Girtyoceras*, *Entogonites*, *Eothalassoceras*, *Dimorphoceras*, and *Pronorites*(?). The beds containing these fossils can be correlated with two divisions of the British Carboniferous section, the upper *Beyrichoceras* (B_2) zone of mid-Viséan and the lower *Goniatites* or *Posidonia* (P_1) zone of late Viséan age.

In the Eagle-Circle district, longitudinally lirate *Goniatites*, *Neoglyphioceras*, and *Girtyoceras* in the lower middle part of the Calico Bluff formation represent the upper *Goniatites* or *Posidonia* (P_2) zone, the highest of the Viséan goniatite zones. At one locality in the same formation, *Cravenoceras* sp. possibly represents the lower *Eumorphoceras* (E_1) zone of early Namurian (late Mississippian) age.

On a small island in Trocadero Bay, Prince of Wales Island, the only known goniatite locality in southeastern Alaska, a limestone contains *Gastrioceras* (*Brannerоceras*) *branneri* Smith and *Glaphyrites* sp. of early Pennsylvanian (Morrow) age.

FURTHER EVALUATION OF THE LARSEN METHOD OF AGE DETERMINATION

David Gottfried, F. E. Senftle, and H. W. Jaffe
U. S. Geological Survey, Washington, D. C.

New data permit a further evaluation of the Larsen method for determining the age of radioactive accessory minerals (zircon, monazite, and xenotime) in igneous rocks from the ratio of total lead to alpha activity.

Agreement between the alpha emission measured by thick-source alpha counting and that calculated from the uranium and thorium content of zircon and monazite indicates the validity of calculated absorption factors.

As a result of metamictization, the indices of refraction of zircon decrease with lead content and permit an order-of-magnitude estimate of the lead content above a threshold of 100 ppm.

Fresh, metamict, and coarse and fine fractions of zircon from the same rocks may contain widely varying amounts of lead and radioactivity. Lead-alpha activity ratios on each fraction give internal checks on zircon within the same rock.

Cross checks on ages obtained by the Larsen method have been made on zircon and monazite on which isotopic ages have been determined, zircon intimately associated with an isotopically dated uraninite, zircon dated by the radiation-damage method of Holland, zircon from rocks on which potassium-argon ages are available, and zircon, monazite, and xenotime from the same rock.

Sources of error are: experimental errors of the alpha counts and lead determinations; presence of common lead; variations from the assumed Th/U ratios; possible susceptibility of minute zircon crystals to lose or gain Th, U, or Pb by diffusion, leaching, or metamorphism; and application of the simplified age equations to rocks older than Cambrian.

POWDER X-RAY DIFFRACTOMETER METHOD OF DETERMINATION OF THE IRON-MAGNESIUM RATIO IN THE PHLOGOPITE-BIOTITE SERIES

John A. Gower
Dept. Geology and Geophysics, Massachusetts Institute of Technology, Cambridge, Mass.

The iron-magnesium ratio in biotite may be determined by measuring the intensity ratio of (004) to (005). This ratio is highly sensitive to iron-magnesium substitution and is virtually unaffected by other substitutions such as Na for K, F for OH, and Al for Si. The intensity method gives adequate precision and appears to be accurate to within about 5 per cent or less of the magnesium-iron content.

Unit-cell measurements are of limited value in the determination of composition. Iron-rich biotites have a shorter c parameter than magnesium members, despite the fact that iron has a larger ionic radius than magnesium. Fluorine produces a marked decrease in c_o. Tetrahedrally co-ordinated Al may cause a slight increase. In metamorphic biotites c_o is larger than in igneous ones. The b_o parameter shows little or no change with iron content but is smaller in fluorine-rich specimens. The a_o parameter seems to show about the same variation as b_o, but the reflections in some specimens are too weak to be identified with certainty by powder methods.

A new form of analysis plot has been used which shows more extensive solid solution with muscovite than has been previously supposed.

PROTODOLOMITE

Donald L. Graf and Julian R. Goldsmith
Illinois State Geological Survey, Urbana, Ill.; Department of Geology, The University of Chicago, Chicago, Ill.

Recorded attempts at dolomite synthesis under earth-surface temperatures and pressures always have yielded metastable assemblages. It is believed that failure to produce dolomite arises from the difficulty of depositing Ca^{++} and Mg^{++} ions in ordered arrangement during rapid crystallization.

The hydrothermal formation of dolomite from a number of carbonate materials has been investigated in the temperature range from 25° to 450° C. Of particular interest among the products are phases yielding x-ray diffraction diagrams with superstructure reflections greatly weakened or absent, and having interplanar spacings corresponding to molar compositions in the range $Ca_{60}Mg_{40}$—$Ca_{50}Mg_{50}$. These materials were produced: (1) from the crystallization of gels, formed by mixing concentrated solutions of K_2CO_3 and of calcium and magnesium chlorides, and then heated at temperatures ranging from 25° to 200° C.; (2) during the hydrothermal treatment of algal and echinoidal magnesium calcites, initially having molar compositions ranging from $Ca_{94}Mg_6$ to $Ca_{79}Mg_{21}$, in the temperature range from 300° to 400°C. These poorly ordered near dolomites, or protodolomites, also have been observed to form during the rapid cooling of dry periclase-calcite assemblages through the dolomite stability field, from temperatures above 500° C.

In view of their relatively narrow compositional range, it appears probable that protodolomites have a relatively high degree of short-range Ca-Mg order, rather than being merely metastable, disordered, high-magnesium calcites. Under the proper conditions, reorganization takes place with the development of long-range order and the 1:1 composition characteristic of normal dolomite.

EVIDENCE OF POLAR SHIFT SINCE TRIASSIC TIME

John W. Graham
Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D. C.

The magnetizations of 343 samples of Permian and Triassic sediments from the United States (southwest, mainly) are compared to magnetizations that have been reported by Clegg, Almond, and Stubbs (1954) for sediments of approximately the same age in England. An impressive number of the observations are in agreement simply on the basis of assuming that the rocks were magnetized by a geomagnetic field about like the one today, the essential difference being that this field was in a significantly different orientation. Other rock-magnetism observations and theoretical considerations indicate that it is not fortuitous that the magnetic and geographic axes nearly coincide today. Hence it can be said that the correlation of the English and American magnetizations suggests that an outer shell of the earth has been translated relative to the rotation axis. In the former orientation the equator would cross Lower California, Arkansas, Massachusetts, Gibraltar, Kenya, and Tasmania. Observations from other continents are necessary for determining the extent to which the outer shell held together as a unit during the translation. The causes for the shift and the time during which it took place are not known.

DENUDATION AND BEACH BUILDING

U. S. Grant
University of California (Department of Geology), 405 Hilgard, Los Angeles 24, Calif.

Although direct measurement of average lowering of the land surface by erosion over large areas is impracticable, measurements of annual or long-period sediment deposits in reservoirs give a fair measure of rate of denudation exclusive of solution removal. Denudation rate in drainage basins directly tributary to a sea coast gives a clue as to supply, and hence removal, of beach-building sediment. Recent studies in California suggest that longshore currents transport beach sediment long distances and also out around rocky points formerly considered rather effective barriers to beach sand travel. Escape of beach sand down submarine canyons must be an important means of removal of the material though "fan" deposits at canyon mouths on sea floor appear undersized in volume, suggesting wide dispersal beyond canyon terminus.

STRATIGRAPHIC NOMENCLATURE IN COAL-BEARING ROCKS

Henry H. Gray
Indiana Geological Survey, Bloomington Ind.

Rock units most practicable for mapping of coal-bearing rocks extend from the top of one coal bed to the top of the coal next above. Where the coal is missing, the stratigraphically equivalent position may be fixed by characteristic associated rocks such as underclay or roof shale. The name *cyclothem* is retained for this mappable rock unit to emphasize its cyclic and coal-bearing aspects.

Cyclothems are better characterized by lateral relationships between rock types than by a single synthetic vertical succession, because no rock type is coextensive with the cyclothem. The boundary of the cyclothem is not of universal extent because the identifying rocks may wedge out or grade laterally into indeterminate types; the resulting rock unit, consisting of two or more cyclothems

locally coalesced, may be called a concyclothem. Coal beds locally present within a cyclothem divide the cyclothem into intracyclothems, identical to but smaller than cyclothems both in thickness and extent.

Most coal beds are named; cyclothems, concyclothems, and intracyclothems may therefore be named for the coal beds included at their tops.

PETROCHEMICAL TRENDS

Jack Green and Arie Poldervaart
California Research Corporation, La Habra, Calif.; Department of Geology, Columbia University, New York, N. Y.

Quantitative limitations are placed on the relations of the main chemical constituents of stony meteorites (6 group averages), igneous rocks (183 group averages), sediments (52 group averages), metamorphic rocks (25 group averages), and dissolved solids in sea water (1 average). These 267 group averages represent about 3000 individual analyses. The averages have been recalculated anhydrous and minus CO_2, after which weight percentages have been converted to ionic weight percentages. For each major rock group the following diagrams are given: (1) variations of different ions, combinations of ions, and ionic ratios against increasing Si; (2) felsic index versus mafic index; and (3) weight per cent triads: (a) Mg − Fe − Na + K (b) Mg − Fe − Ca (c) Mg − Ca − Al (d) Ca − Al − Na + K (e) Al − Fe − Na + K (f) Ca − Mg − Na + K (g) Mg − Al − Na + K (h) Mg − Fe − Al (i) Al − Fe − Ca (j) Fe − Ca − Na + K.

In all rock processes there is a separation of felsic and mafic phases but, whereas in igneous and metamorphic processes there is a felsic "front" and mafic "rear", in sedimentary processes the residuum is felsic, the "front" mafic. The gradual addition of volatiles and alkalis to the continental upper crust in geologic time is contrasted to the more abrupt differentiation of the mantle into mafic and silicon-aluminum-rich phases. The diagrams indicate that differentiation of igneous rocks may have stemmed from mantle rocks of chondritic affinity producing as a differentiate oceanic basalt and dunitic rocks. The lack of trend of Na and K in time for basaltic rocks supports the theory that basalts are tapped from the mantle.

SAMPLING SEDIMENTS FOR MEASUREMENT OF GRAIN SIZE AND SHAPE

John C. Griffiths
Department of Mineralogy, The Pennsylvania State University, University Park, Pa.

Samples are analyzed to estimate characteristics of populations; random selection ensures that samples are suitable for this purpose. Sampling sediments requires random selection from stratified populations, and, for comparisons among populations, random samples proportional in number to the variability within strata are most efficient. The actual sampling pattern, determined empirically, depends upon specific purpose, property measured, and sedimentary process represented.

Estimation of mean grain shape requires a sampling pattern which differs among rock types; few samples of many grains should be analyzed in sediments near their source—*e.g.*, till and many arkoses; many samples of few grains should be analyzed from sediments which have suffered intense selective sorting—*e.g.*, far-travelled sediments such as quartzites and beach sands. Intermediate types require individual determination of the most efficient apportionment of samples and grains.

Fifty grains from each of five samples from three outcrops of Pottsville quartzite in central Pennsylvania indicate that the most efficient pattern requires 25 to 30 grains and 10 samples per outcrop if outcrops 1 mile apart are to be differentiated in terms of mean grain size.

After measuring 30 grains in 10 fields of 25 thin sections from ore-bearing and barren sandstones in the Morrison formation of the Colorado Plateau the optimum sampling ratio is 20 grains from 2 fields per thin section. To detect a difference in grain size between ore-bearing and barren sediments would require 150–200 thin sections (rock samples).

JADEITE, ANALCITE, AND NEPHELINE-ALBITE EQUILIBRIUM

D. T. Griggs, W. S. Fyfe and G. C. Kennedy
Institute of Geophysics, University of California, Los Angeles, Calif.

More than 100 runs have been made with the "Simple Squeezer" to define the field of jadeite equilibrium. The prior work of Birch, Robertson, and MacDonald (unpublished) on the equilibrium between jadeite and nepheline-albite has been confirmed within our experimental error. Yoder's measurements on the nepheline + albite + water → analcite equilibrium have been confirmed and substantially extended. The jadeite-analcite boundary extends from the triple point at about 600° and 12 kilobars, to about 300° and 18 kilobars. Equilibrium has been checked by forming jadeite from analcite and forming analcite from jadeite + water.

The apparatus is simple, cheap, and easy to operate. It is suitable for exploration of many reactions of importance in the earth's crust. Pressures attainable are: 100 kilobars at 25°C, 50 kilobars at 500°C, and 10 kilobars at 1000°C. Precision of measurement is 5 per cent in pressure and 5°C in temperature.

The sample, a few milligrams of powder, is compressed between two piston faces a quarter of an inch in diameter. It is separated from the piston by platinum foil and retained by a thin stainless-steel ring. The platinum bonds to the stainless steel, forming a capsule which retains water pressure at the highest temperatures. Water is usually introduced as initial water of hydration. X-ray analysis is used entirely for identification of phases.

SODIUM AND POTASSIUM CONTENT OF MUSCOVITES FROM THE PEERLESS PEGMATITE, BLACK HILLS, SOUTH DAKOTA

Thomas B. Grootemaat and Heinrich D. Holland
Department of Geology, Princeton University, Princeton, N. J.

The sodium and potassium content of muscovites from the various zones of the Peerless pegmatite, Black Hills, South Dakota, was determined flame photometrically. The potassium-sodium ratio varies systematically from the wall to the core of the pegmatite. Values between 13 and 31 were found, corresponding to a range of 13 to 5 mol per cent respectively of paragonite in the muscovite structure. Since in all the zones studied the muscovite is accompanied by albite or cleavelandite, the sodium content of the muscovite is the maximum possible at the temperature and pressure of formation. The position of the solvus in the paragonite-muscovite system can thus be used to estimate the temperature of formation of the muscovite samples. The present data suggest crystallization temperatures of approximately 500°C for the outer zones and of approximately 350°C for the core of the pegmatite.

NEW OBSERVATIONS ON EARLIEST AMMONITE ONTOGENY

Otto Haas
The American Museum of Natural History, New York, N. Y.

During revision of the Jurassic (early Oxfordian) ammonite fauna of Mount Hermon, Syria, about 15 innermost nuclei of a species of *Ochetoceras* (*Campylites*) offered excellent opportunities for study of the earliest ontogeny. Branco's observations of 1879–1880 were largely confirmed; beyond that, the caecum (the bubble with which the siphuncle starts) could be observed in several nuclei and even laid entirely free in one so that it can be viewed three-dimensionally. The ontogenetic transition from the prosuture, with a median saddle, to the later sutures, with median lobes, is brought about by the first (or primary) and second sutures which are only rarely well discernible; accordingly, they have not been recognized correctly by previous workers. The primary septum does not reach the outer surface with its median portion but plunges under the median saddle of the prosuture, resting on the proseptum just apicad of the caecum.

LOWER CARBONIFEROUS SPORE ASSEMBLAGE IN COAL FROM THE SOUTH NAHANNI RIVER AREA IN NORTHWESTERN CANADA*

P. A. Hacquebard
Geological Survey of Canada, Coal Research Section, Sydney, N. S.

Field relations in the South Nahanni river area, situated in the N.W.T. at 123°59′ west and 61°06′ north, indicated the presence of a Carboniferous coal deposit.† Such deposits have not previously been reported from western Canada, the known Carboniferous strata being of marine or near shore deposition.

The small spore assemblage from this coal contains numerous types that greatly vary in form and sculpturing. Those with equatorial thickenings and ridges, belonging to the suite *Cingulati* Potonie & Klaus 1954, predominate. In all 15 genera and 58 species are recognized, including 3 new genera, 35 new species and 10 new types of which only one or two specimens were found.

The following known genera are present, numbers of species are in parentheses: *Calamospora* (2); *Punctati-sporites* (10); *Granulati-sporites* (2); *Reticulati-sporites* (3); *Triquitrites* (3); *Tripartites?* (1); *Lycospora* (2); *Simozonotriletes* (1); *Denso-sporites* (12); *Cirratriradites* (2); *Reinschospora* (3); *Microsporites* (1).

A remarkable similarity occurs between this assemblage and the one reported from Lower Carboniferous coals in northern Russia. Therefore a Lower Carboniferous flora is thought to be represented, but the majority of the species encountered have not previously been reported from the Mississippian of North America.

This floral similarity might perhaps indicate the presence of a continental facies of Lower Carboniferous strata between the Nahanni river and northern Russia, through the arctic. This assumption may be supported by the assumed Carboniferous coal deposits of the Parry Islands, and the Lower Carboniferous coals of Spitzbergen and Bear Island.

GEOMORPHIC-PEDOLOGIC STUDY OF TWO LAND SURFACES IN THE HIGH PLAINS OF EASTERN WYOMING

R. F. Hadley and B. N. Rolfe
U. S. Geological Survey, Denver, Colo.

The Cheyenne River basin in eastern Wyoming is characterized by its youthful geomorphic stage and skeletal soils. Remnants of older land surfaces bearing mature soils are therefore unusual. Geomorphic and pedologic evidence indicates that an upland erosion surface on the Wasatch formation and a high terrace, cut in alluvium derived from the Brule clay, are both older than similar land surfaces developed generally at lower levels throughout the watershed.

The Wasatch surface which covers the western part of the Cheyenne basin is conspicuously undissected in an area otherwise being actively eroded. The advance of an eroding front toward the Wasatch surface has been impeded by resistant clinker beds capping the Fort Union formation. The terrace above Prairie Dog Creek, in the eastern part of the basin, is preserved as remnants along interstream divides.

Soil profiles on both surfaces are mature. That on the Prairie Dog terrace is a well-defined grassland soil, probably of the Chestnut group. Horizonation and soil structure are distinct. At this site a single profile has developed from two deposits of soil material. The Wasatch soil is also well devel-

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† A sample of coal from this area was collected by Mr. W. J. H. Patton, post graduate student at the University of Alberta and submitted to the author by Dr. J. D. Campbell, Palaeobotanist, Alberta Research Council, Edmonton, Alberta

oped and in addition retains podzolic characteristics from a more humid past. The B horizon has a distinctive clay bulge along with well-defined soil structure. Clay skins on peds in the subsoil are similar to those of Sangamon soils of Nebraska. There is no evidence to suggest that the soils are contemporaneous.

INTERPRETATION OF THE ONTOGENY OF A LOWER CRETACEOUS BELEMNITE

Tetsuro Hanai
Department of Geology, Louisiana State University, Baton Rouge, La.; Geological Institute, University of Tokyo

The Lower Cretaceous deposits of the Miyako district of Japan contain many specimens of *Neohibolites*. The well-preserved specimens in the calcareous sandstones exhibit the following detailed internal structures: (1) a siphuncle migrating to a subcentral position as the protoconch is approached, (2) the presence of an intermediate camera between the protoconch and the primordial rostrum, (3) a primordial rostrum consisting of a series of conelike thick plates. Two stages of shell development may be distinguishable for *Neohibolites miyakoensis* Hanai: (1) an embryonic stage, and (2) a belemnoid stage. In the embryonic stage, the protoconch and the primordial rostrum develop with an intermediate camera between the two. The formation of the first camera occurs with the siphuncle present near its center. The siphuncle originally subcentral gradually becomes ventral. The succeeding belemnoid stage is characterized by the presence of a ventral siphuncle and a true rostrum. This stage can be divided into three substages on the basis of the shape of the rostrum. The first substage is characterized by a conical but extremely attenuated rostrum. In the second substage there is a slender, clavate rostrum which is similar to that in the Jurassic genus *Hibolites*. The stout, clavate adult rostrum characteristic of *Neohibolites* is developed as a third substage.

EFFECTS OF GAMMA RADIATION ON THE EXPERIMENTAL DEFORMATION OF CALCITE

J. W. Handin, D. V. Higgs, D. R. Lewis, and P. K. Weyl
Shell Development Company, 3737 Bellaire Blvd., Houston, Texas

Yule marble and calcite single crystals were deformed dry at room temperature under a constant confining pressure of 2750 bars at a strain rate of 1 per cent per minute. Uniaxial compression and extension experiments were made; for the marble, parallel and normal to the c axis fabric maximum; for the single crystals, parallel to the c axis and normal to $m\{10\bar{1}0\}$. Yule marble exposed to 17 megaroentgens of gamma radiation before deformation turned from white to bright blue when deformed. Intensity of color varied with orientation and degree of strain. Irradiated single crystals changed from amber to bright blue when the greatest principal stress paralleled the c axis. No color change occurred when the least principal stress paralleled c. Irradiation usually resulted in small reductions in yield stress.

Petrographic studies of the single crystals proved that established principal deformation mechanisms, twin gliding on $e\{01\bar{1}2\}$ and translation gliding on $r\{10\bar{1}1\}$, were still operative and confirmed that blue color was associated with translation gliding only. In Yule marble blue grains deformed by translation gliding, clear grains by twin gliding.

Thermoluminescence studies indicated that compression along c yielded a new peak in the glow curves, not present in undeformed irradiated calcite. Extension along c increased the magnitude of the glow curve, at about 240°, but gave rise to no new peaks.

STABILITY OF SMITHSONITE

R. I. Harker and J. J. Hutta
Dept. of Geophysics & Geochemistry in the Div. of Earth Sciences, The College of Mineral Industries, The Pennsylvania State University, University Park, Pa.

The univariant P_{CO_2}-T curve for the reaction $ZnCO_3 \rightleftarrows ZnO + CO_2$ has been determined.

Between 1000 and 3000 atmospheres the P-T curve for smithsonite lies above 350° and below 450°C.

At 2000 atmospheres an equilibrium temperature of about 400°C is obtained, which may be compared with 850°C for magnesite and 900°C for dolomite at the same pressure.

PETROGRAPHIC COMPONENTS AND STOKER COAL TESTING

John A. Harrison
Illinois State Geological Survey, Urbana, Ill.

Petrographic analyses of stoker coals tested at Illinois Geological Survey have been resumed and preliminary results are given.

Polished surface techniques are used in present petrographic analyses. Vitrinite, exinite, inertinite, and mineral matter were considered in the first of two series of analyses. In the second series a more detailed analysis was desirable, therefore vitrinite minus 24 microns, vitrinite plus 24 microns, exinite, resin rodlets, micrinite, semifusinite, fusinite and mineral matter were considered.

Data obtained show the relationship of petrographic components to combustion characteristics as outlined in the stoker tests; however, the effect of the petrographic components are not equally indicated in all five combustion characteristics. These characteristics are uniformity of combustion, responsiveness, pickup, overrun, and heat obtained. Indications are that vitrinite has an effect upon uniformity of combustion and responsiveness but little on overrun and heat obtained.

Indications are that amount, occurrence and distribution of petrographic components within the coal affect the combustion characteristics. Effect of the vitrinite, which makes up the largest portion of the Illinois coals, appears to be modified by the amount of inertinite.

A comparison between chemical properties and petrographic components has been made. In this study a trend shows an increase in heat value with an increase in inertinite.

This is only a preliminary report, but results show that additional study is warranted.

TURBIDITY CURRENTS FROM THE MADGALENA RIVER, COLOMBIA

Bruce C. Heezen
Lamont Geological Observatory, Palisades, N. Y.

The history of the Magdalena River of Colombia provides dramatic evidence that turbidity currents periodically form in fluvial sediments at the mouths of great rivers. On several occasions the destruction or sudden lowering of the Magdalena River mouth bar was followed by the breakage of a submarine cable which crosses the Magdalena submarine canyon in about 700 fathoms, about 15 miles seaward of the river mouth. In 25 years this cable broke 14 times in the vicinity of the canyon. The cable parted under great tension and on several occasions was reported tightly wrapped with green grass. The periods of frequent cable breakage can be correlated with the progress of river-improvement projects which caused the deepening of the bar. The turbidity currents probably ran the length of the Magdalena Submarine Canyon and out onto the Colombia Abyssal Plain where they deposited their load of sediments.

The characteristic occurrence of submarine canyons off contemporary as well as great Pleistocene rivers led to the suggestion that turbidity currents which formed in the submarine fluvial deposits near these river mouths had eroded the associated submarine canyons. This evidence of modern turbidity currents formed by the destruction of the Magdalena River bar gives further proof of the turbidity-current origin of submarine canyons and demonstrates that river deltas are the temporary sites of deposition of sediment which later is carried farther down the submarine slopes by turbidity currents.

SIGNIFICANCE OF THE GRAVIMETRIC METHOD IN GEOPHYSICS AND GEOLOGY

W. A. Heiskanen
Ohio State University, Columbus, Ohio

The gravimetric studies of Helmert, Hayford, Bowie, Bonsdorff, de Graaff Hunter, Vening Meinesz, Bullard, Tsuboi, Browne, the author, and others, and the extensive isostatic reductions of gravity

anomalies by different geodetic and geophysical institutions have indisputably shown that isostatic equilibrium of topographic masses exists in broad lines. Light roots of mountains and antiroots of heavier material under ocean bottoms compensate disturbing topographic masses. By isostatic reduction of gravity anomalies we have discovered that the normal thickness of the earth's crust is about 30 km; at ocean coasts (Vening Meinesz) 20 km; and under mountains, 40 to 50 km, depending on the mountain's elevation. On the other hand, seismological studies of oceans by Ewing, Worzel, and Hess indicate thickness of the earth's crust (Moho-discontinuity) under oceans to be only about 5 km. Thus gravimetric as well as seismological studies testify that isostatic equilibrium is the rule and that deviations from the equilibrium are the exceptions. About 85 to 90 per cent of the mass deficiency of oceans and of the mass surplus of most high mountains is isostatically compensated. Significance of the gravimetric-isostatic studies of the earth's crust is evident. We recall only the basic value of the belts of negative gravity anomalies. Most fruitful and interesting are the gravimetrical and seismological studies of the deviation areas from the isostatic equilibrium and of the phenomena which cause them.

SEISMIC OBSERVATIONS IN DEEP AND SHALLOW WATER SOUTHEAST OF NORTH CAROLINA AND SOUTH CAROLINA

J. B. Hersey, R. S. Edwards, H. R. Johnson, and Elizabeth T. Bunce
Woods Hole Oceanographic Institution, Woods Hole, Mass.

Seismic-refraction and reflection observations have been made over an area extending about 250 miles southeastward from the coast of North Carolina and South Carolina to discover what, if any, structural relation exists between the Cape Fear Arch and a topographic ridge extending out from the continental slope off Cape Fear and curving and plunging southward to the Bahamas. Seismic-refraction results on the continental shelf demonstrate the extension of the Cape Fear Arch out under the shelf, and deep-water refractions indicate that the topographic ridge is also a structural ridge involving the full thickness of the Earth's crust to the Mohorovičić discontinuity. The observations admit the possibility that the Cape Fear Arch continues as a structural unit across the continental slope into North American Basin.

RESIDUAL SOILS OF THE WEST SLOPE OF THE SIERRA NEVADA AND THEIR ENGINEERING PROPERTIES

C. P. Holdredge
Corps of Engineers, Wright Building, Sacramento, Calif.

The west slope of the Sierra Nevada is underlain by a basement complex of pre-Cretaceous metamorphic and granitic rocks with an average chemical and mineralogical composition of granodiorite and by Tertiary basaltic, andesitic, and rhyolitic flows and sediments. The foothills are underlain by middle Tertiary volcanic sediments, upper Tertiary quartzose sands and bentonitic clays, Quaternary alluvial fans of arkosic sands and clays, and Recent stream deposits of arkosic sands and gravels.

Four major weathering cycles since Cretaceous time have left remnants of residual soils produced by the first three. The present cycle, dating from early Pleistocene and varying in temperature and rainfall from north to south and east to west and with time, has formed residual soils on all but the Recent deposits.

Residual soils on metamorphic rocks are usually thin, stony, clayey, plastic, and impervious but lack stability. Granitic soils are usually deep, nonplastic, and of high density and strength but are relatively more pervious. Soils on Tertiary volcanics are variable, but their properties average between those of metamorphic and granitic soils. Soils on late Tertiary and Quaternary sediments approach granitic soils in their characteristics but generally contain more clay and frequently develop hardpans or claypans.

CONODONTS IN THE WINNIPEG FORMATION (ORDOVICIAN) OF NORTH DAKOTA*

F. D. Holland, Jr. and Charles H. Waldren
Geology Department, University of North Dakota, Grand Forks, N. D.

Until Strassberg (1954) reported them from the Winnipeg formation in the Stanolind Oil and Gas Company, Walter and Ingeborg Waswick No. 1, Ward County, conodonts had been mentioned only twice from North Dakota. In this well, specimens occur abundantly in the basal sandstone unit of the Winnipeg formation at 11,000 feet in thin bands in a clean quartz sandstone which is fine- to coarse-grained, subangular, frosted to clear, and friable. These specimens have been studied and placed in 13 species (one new) in 6 genera.

The Winnipeg formation, which crops out on the southern shores of Lake Winnipeg, Manitoba, Canada, consists of a basal quartzose sandstone unit and an overlying dark-green, waxy, fossiliferous shale unit. This is overlain by the carbonate sequence of the Cincinnatian Red River formation. As herein discussed, earlier workers have likened this lithologic sequence to similar sequences in northern Illinois and the Black Hills but have disagreed as to whether the Winnipeg sandstone is Cincinnatian (Upper Ordovician) or Trentonian (Middle Ordovician).

The conodont fauna studied, especially the genera *Microcoelodus* and *Acontiodus*, strongly suggests that the basal sandstone unit of the Winnipeg in North Dakota is older than Cincinnatian and may be Blackriverian or Chazyan.

CRABS FROM THE CANNONBALL FORMATION (PALEOCENE) OF NORTH DAKOTA*

F. D. Holland, Jr., and A. M. Cvancara
Dept. of Geology, University of North Dakota, Grand Forks, N. D.

More than 50 specimens of fossil crabs have been collected from the Cannonball formation (Paleocene) of southern Morton and Burleigh counties, south-central North Dakota. This is the first report of fossil crabs in North Dakota.

The crustaceans are excellently preserved; carapaces with legs and abdomen commonly preserved allow almost complete restoration. In all the specimens the original material of the exoskeleton is preserved virtually unaltered.

The crabs occur in grayish-red, medium-grained sandstone nodules which, in turn, are usually found in a light olive-gray unconsolidated sand in the lower Cannonball formation. In a few cases, the nodules are in a poorly consolidated sandstone higher in the formation. Harder sandstone "tubes" control the shape of the nodules which are commonly subspherical or elongate.

The crab carapace is suboval, slightly longer than wide, and strongly convex both longitudinally and transversely with a relatively smooth surface and poorly defined body regions. These crabs seem to have little affinity with established genera and species and are made the basis of a genus and two new species in the Family Raninidae. All but two of the specimens are placed in one species.

Associated faunal remains include shark teeth, fish scales and bones, and a few gastropods and pelecypods; *Teredo*-like borings preserved in petrified wood are also characteristic of this zone.

This unusual occurrence of abundant fossil crabs suggests a near-shore condition of the Cannonball sea in this portion of North Dakota.

MEETING OUR RESPONSIBILITIES

Chauncey D. Holmes
208 Swallow Hall, Univ. of Missouri, Columbia, Mo.

Although much of the general-educational value of geology lies in its essential inclusion of basic principles of other natural sciences, still more valuable is the essence of geology itself: history of the

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Earth and evolution of its inhabitants. This necessary involvement with the other sciences can result in introductory courses replete with applied chemistry and physics and the mechanics of landscape development, with (from the student's viewpoint) an incomprehensible afterthought summarizing what should be the main theme—Earth history. To the extent that such relative neglect of Earth history prevails, the educated public is denied the chance to gain a true appreciation of geologic science. This aids the shift of educational attention to devices such as survey courses.

Our first responsibility is to organize the other sciences around the science of Earth history and evolutionary development, so that our students may learn to interpret the geologic past, at least in elementary fashion, rather than devoting a disproportionate share of their available time to the refinements of Huttonian keymaking. Such an introductory course affords appropriate background for any type of future specialization. It meets our obligations to both future geologists and non-geologists.

New discoveries and techniques in geochemistry and geophysics will enrich, but never supersede, the study of Earth history. By judicious selection and sound pedagogical organization, geology will improve its essential scientific services and its pre-eminent contributions to general education.

MINERALOGY AND PETROLOGY OF THE MANGANESE PROTORE AT THE MERID MINE, MINAS GERAIS, BRAZIL

Arthur Horen

Raw Materials Division, U. S. Steel Corporation, 525 Wm. Penn Place, Pittsburgh, Pa.

The Merid Mine is located at Morra da Mina in the Lafaiete District of south-central Minas Gerais. The country rocks are a part of the Minas series and are Proterozoic in age. They consist of quartzites, greenschists, manganese carbonate-silicate rocks, manganese oxides, amphibolites, graphitic schists, and a variety of intrusives.

Field and laboratory studies indicate that the protores are metamorphosed sediments which originally probably consisted of banded manganese carbonates interlayered with cherts or mudstones. It is believed that virtually all the manganese is derived from these sediments rather than from an igneous source.

The manganiferous sediments have undergone at least two stages of regional metamorphism resulting in rocks locally termed "carbonate-silicate" and essentially composed of spessartite and rhodochrosites; spessartite and quartz; or spessartite, rhodochrosites, and minor silicates. Accessories include graphite, pyrophanite, neotocite, bementite, thulite, manganoan apatite, and rare sulfides. The neotocite occurs as a decomposition product of rhodonite. Near the contact with the amphibolite the garnets are somewhat richer in iron and magnesium, and a manganoan cummingtonite is found.

In proximity to the intrusives the protores show the effects of contact metamorphism. They contain little carbonate and are rich in tephroite and/or rhodonite in addition to spessartite. Hydrous silicates such as bementite and thulite are found locally, particularly near pegmatites. The occurrence in veins of massive rhodonite with spessartite and rare pyrite is attributed to processes of metamorphic differentiation probably abetted locally by hydrothermal activity related to the intrusion of the younger granite.

GEOLOGICAL PROBLEMS IN HIGHWAY ENGINEERING, MISSISSIPPI ALLUVIAL VALLEY OF LOUISIANA

Leo W. Hough

Louisiana Geological Survey, P. O. Box 8847, University Station, Baton Rouge, La.

The major problems in highway construction in the lower Alluvial Valley of the Mississippi in Louisiana are (1) excessive settlement, (2) stability of foundations and embankments, and (3) adequate subgrade for the pavement.

The soils in the alluvial valley which the highway engineers must use consist predominantly of Recent clays, silts, silty clays, and fine silty sands. In many areas considerable organic material is mixed with the soil. In the Deltaic-plain and coastal-plains environment, many of the swamp and marsh areas have deposits 10–30 feet thick of mixtures of soft clays and organic matter called muck and mucky clays. These mucks are extremely unstable and must be removed to construct stable embankments and roadways. The clays and silty clays of the Deltaic plain and backswamp areas in the Tensas and Boeuf basins are unstable and especially susceptible to excessive settlement.

Subgrade failures which result in excessive breaking and cracking of pavement are caused by these same unstable clays, silty clays, and organic clays and silts.

Highway engineers have solved the problems presented by the unstable alluvial soils by scientific construction based on the results of geologic and engineering studies. It has been possible by the selection of materials, proper compaction, and other scientific construction methods to build highways in the alluvial valley which will carry the modern high-speed heavy traffic and stand up under the daily pounding of heavy vehicular loads.

FOUNDATION PROBLEMS DURING CONSTRUCTION OF ALGIERS LOCK AND CANAL, LOUISIANA

Herman A. Huesmann
New Orleans District, Corps of Engineers, New Orleans, La.

Algiers Lock and Navigation Canal, built by the Corps of Engineers to provide an alternate connection between the Mississippi River and the Intracoastal Waterway, are located in an area underlain by Recent and Pleistocene soils typical of the New Orleans area. Foundation problems common to the area were experienced while building structures along the canal. During excavation for construction of the lock it was necessary to reduce gas and hydrostatic pressures in underlying Recent sand strata and excavate very gentle slopes to prevent upheaval of the bottom and failure of the slopes. Piles were used to transfer the weights of the structures through the Recent to less compressible Pleistocene strata in order to reduce settlement. Flow of gas from sand stratum through the piles required construction of outlet passages to prevent the gas from affecting the concrete above the piles.

Vertical sand drains extending to depths of 60 feet were used to accelerate consolidation of Recent clays beneath approach embankment and abutment areas of highway-bridge crossing. Records of periodic measurements show the amount and rate of settlement, and comparison of borings made before and after construction of the approaches illustrates the change in water content which occurred in the foundation soils. Lateral movement of the bridge piers during construction was reported, and investigation to ascertain their stability was made.

DEPOSITION OF PERMIAN SANDSTONES IN THE DELAWARE BASIN, TEXAS, AND NEW MEXICO

Joseph P. D. Hull, Jr.
Department of Geology, Columbia University, New York, N. Y.

The Delaware Mountain group, Texas and New Mexico, is 3000 feet of a deep-water, terrigenous facies, almost encircled by contemporaneous reef limestone. Abundant detrital feldspar in basin rocks and in corresponding fine sand grains to the north and northeast suggests back-reef sources of basin sands.

Some basin sands are small enough to have been carried by wind, but no feature indicates its necessity. Scarcity of clay in Guadalupian rocks may have resulted from source and history of weathering or from sorting during transport. Ripple marks, channeling, aligned fusulines, and flow casts in basin rocks indicate bottom currents directed basinward. Even distribution of sand with

slight thickening basinward reflects control of deposition in deep water by gravity and submarine topography. Reefs were partial barriers to sand transport, since some back-reef sandstones are coarser than basin rocks.

Upper Guadalupian basin rocks are cyclic, typically with successive units of thin clastic limestone, laminated sandy siltstone, and massive fine-grained sandstone, totaling more than 100 feet. These cycles are interpreted as deposits controlled by rates of relative subsidence. Some calcareous debris spilled into the basin when subsidence permitted active reef growth and deposition of carbonate material and evaporite in shallow water. Quartz sand was masked by nonterrigenous deposits. As subsidence slowed, quartz sand was sorted in shallow water, and fine grains reached the basin to form laminated beds. When relative subsidence ceased, sand was transported to the basin and deposited rapidly by turbidity currents as massive beds. This repeated depositional cycle caused concentration of sandstone in the deep-water facies.

SCHEELITE IN FELDSPATHIZED GRANODIORITE, GABBS DISTRICT, NEVADA

Fred L. Humphrey and Michael Wyatt
School of Mineral Sciences, Stanford University, Calif.

Economic quantities of scheelite occur in a sheared and feldspathized portion of the Illinois granodiorite stock, near Gabbs, Nevada. The granodiorite intrudes dolomite and shale of probable Late Triassic age.

A westward projection of the stock, and adjacent sedimentary rocks, was subjected to strong compressive forces during or shortly after the emplacement of the granodiorite. The dolomite is thrust over the granodiorite, and the latter is intensely sheared for several hundred feet from the contact. The scheelite mineralization is one stage of a metasomatic replacement process; the metasomatizing solutions were guided by the shear and fracture zones. The mineralogical changes effected are concentrated where crushing and fracturing were most intense, and particularly where there was recurrent crushing. Four successive stages of metasomatic alteration can be recognized:

(1) Feldspathization; the dominant process is replacement of quartz by orthoclase and oligoclase

(2) Introduction of more plagioclase, accompanied by minerals such as garnet, diopside, and hastingsitic amphibole, forming "Ore-type" rocks

(3) Scheelite mineralization, essentially confined to those "Ore-type" rocks which have been subjected to later crushing

(4) Quartz veining

In spite of the intense crushing no mylonitic rocks were observed, the feldspathized rocks are commonly coarse-grained, and low-temperature minerals such as clay minerals and chlorite are generally absent. These features indicate a high temperature for the mineralization, which probably took place while the intrusion was still hot.

ROLE OF WATER IN THE CRYSTALLIZATION OF THE TOW LAKE GABBRO SILL, NORTHERN MANITOBA

Hugh E. Hunter
1013 E. Louisiana St., Norman, Okla.

The Tow Lake gabbro in the Barrington Lake district, northern Manitoba, was intruded between horizontal metasedimentary and metavolcanic rocks of Precambrian age. The lower two-thirds of the sill is uniform gabbro containing plagioclase (An_{60}) and pyroxene with traces of hornblende. The upper one-third of the sill contains plagioclase (An_{55}), pyroxene, hornblende, and minor amounts of biotite and quartz. Biotite and quartz occur throughout the upper one-third of the sill but are some-

what more plentiful toward the top. The sill apparently crystallized without undergoing differentiation except for a slight concentration of late-crystallizing minerals in the upper part of the sill.

The hydrous minerals indicate that the magma contained an appreciable amount of water. As a result of the pressure gradient in the magma, the water tended to be concentrated in the upper part of the magma chamber. The water lowered the freezing point of the silicate minerals according to its distribution, and consequently silicate minerals crystallized first at the base of the sill. Crystallization took place from the base upward, and gravitative crystal settling was not possible. As a result of reaction of early-formed silicate minerals with the rest magma, the sill consolidated as an essentially homogeneous body of gabbro throughout the lower two-thirds. The original concentration of water toward the upper part of the sill plus upward displacement of volatiles, and to a minor extent of constitutents with low melting point, formed a slightly more acid zone in the upper third of the sill.

RATIO OF THORIUM TO URANIUM IN ZIRCON, SPHENE, AND APATITE

P. M. Hurley and H. W. Fairbairn
Mass. Inst. of Technology, Cambridge, Mass., and U. S. Geological Survey; Mass Inst. of Technology, Cambridge, Mass.

Zircon, sphene, and apatite are important host minerals for uranium and thorium in igneous and metamorphic rocks. Several dozen samples from widely scattered localities were analyzed for these elements to observe variations in their relative abundance. Analyses were made by scintillation spectrometer.

The ratio Th/U is remarkably constant for accessory zircons separated from individual granite plutons. Average values for the following areas are: Eastern Massachusetts, 0.6; Nova Scotia, 0.2; Northern Maine, 0.6; Sudbury, Ontario, 0.3; Miscellaneous, 0.6. In granite zircons in general, therefore, 90 per cent of the radioactivity is due to the uranium series.

In large crystals of zircon from pegmatites the ratio is more varied with a tendency to be higher in the more radioactive samples. Average ratios for areas are: Ontario, 0.5; Carolinas, 2.2; Oklahoma, 5; Ceylon, 0.1; Miscellaneous, 1.2.

Samples of sphene were found to be quite varied but with average values similar to pegmatite zircons. Coarsely crystalline apatite samples were found to be relatively rich in thorium with ratios commonly exceeding 10. The average ratio for accessory apatite is 1.3. If igneous rocks have an average Th/U ratio of about 3, there must be an enrichment of thorium relative to uranium elsewhere in the rock, other than in these minerals.

PEGMATITE MINERAL DEPOSITS OF THE ALTO LIGONHA AREA, PORTUGUESE EAST AFRICA

Richard W. Hutchinson and Richard J. Claus
% American Metal Co. Ltd., 25 Adelaide St. W., Toronto, Ont., Canada

Pegmatite bodies that contain columbite, beryl, lepidolite, bismuth, and mica occur in the Alto Ligonha region of Portuguese East Africa. Pegmatites containing these economic minerals are restricted to belts of metamorphic schists, while pegmatites in granitic rocks are barren.

Mining of columbite-bearing eluvial gravels derived from weathering of the pegmatites is economically feasible, but exploitation of the pegmatites themselves has had limited success. A detailed study of the pegmatites was carried out to determine why pegmatite mining had proved uneconomic at depth and whether selective mining could bring about increased yeilds of the economic minerals. The internal structure of the bodies and the relationship of economic minerals to internal structure offer a solution to these questions.

The internal structure of the pegmatites is very similar to that of comparable bodies in many

districts of the United States and Canada. The same mineralogical assemblages are present, and these occur in the same sequence from walls inward. This is thought to be further support for the concept of origin by crystallization in a restricted system for the zoned pegmatites. Two zones within the pegmatites of the Alto Ligonha area appear to have been formed partially by replacement, but this process has been of only minor importance in pegmatite genesis.

There seems to be a regional zoning of pegmatites in the area based on the presence or absence of lithium minerals. Pegmatites lacking lithium minerals have a simpler internal structure than lithium-bearing bodies.

PETROLOGY OF SIXMILE INTRUSION, LLANO COUNTY, TEXAS

Robert M. Hutchinson
Kansas State College, Manhattan, Kans.

Sixmile intrusion covers a 30–35 square-mile area and consists of one large and several smaller intrusions of fine-grained, light-gray granite (leuco-quartz monzonite and quartz monzonite). "Larsen-method" age determinations give 822 million years.

Intrusion occurred mainly along folds. Biotite fabric diagrams show concordance with wall rocks in many places. Straight-line contacts with metamorphic wall rocks containing older intrusives indicate failure occurred with relatively sudden application of stress under plutonic conditions. Partial rotation of small fault blocks occurred prior to intrusion of Sixmile granite.

There are separate intrusions of Sixmile granite, aplogranite, and medium granite commonly with (1) central areas free of xenoliths; (2) narrow peripheral zones containing up to 80 per cent xenoliths with varying replacement; (3) outer migmatite-like zones often with ptygmatic folds; and (4) distant wall rocks affected only by severe regional metamorphism. Slator granite gneiss appears to grade into medium granite and contains rounded grains of zircon indicating it is probably recrystallized Valley Spring gneiss.

Normative compositions of Sixmile granite have approximate ratios 1:1:1 for quartz:orthoclase:albite. Modal ratios of quartz:microcline:plagioclase approximate 1:1:1 also. SiO_2 plots for Sixmile granite are grouped 70.2–73.4. Oxide plots fail to fit Harker variation diagrams for igneous rocks of this petrographic province. Sixmile values are higher in Al_2O_3, Na_2O, CaO, and MgO and lower in K_2O and FeO. Plagioclase is generally higher, biotite lower, and hornblende lower but more variable than biotite. Biotite averages less than 5 per cent.

VIRGILIAN ARENACEOUS FORAMINIFERA OF EASTERN KANSAS

H. Andrew Ireland
Department of Geology, University of Kansas, Lawrence, Kans.

Several thousand arenaceous Foraminifera were recovered from the insoluble residues of the limestone of the Virgilian Series in eastern Kansas. Identification includes 50 species and 16 genera of which 2 genera and 16 species are new. Most of the forms are Ammodiscinidae and with Textulariidae constitute 80 to 90 per cent of the specimens found. Solution of the limestones destroyed the calcareous Foraminifera but liberated clean, unweathered, well-preserved, nearly perfect specimens, which offsets the loss of embedded forms which could never be extracted.

The collection shows unusually well the essential distinguishing characteristics between *Tolypammina* and *Ammovertella*, for a large number of perfect specimens and hundreds of well-preserved broken forms were available for study. Several species of *Ammobaculites* formerly transferred to the calcareous genus *Endothryranella* are restored to their true classification as arenaceous forms, based on the evidence from the Kansas samples. Abundant evidence for isomorphism is found in the fauna. The evolutionary relationships of *Ammodiscus* and *Ammovertella* are shown by an attached form of an intermediate new genus and by gradations among the large number of *Ammovertella* studied.

Specimens of what are probably the earliest *Astroorhiza* and *Verneuilina* were found. Most of the species show a large stratigraphic range and are useless for subdivision of the Virgilian, but the assemblages have more distinctiveness. The insoluble residues show that even the purest of the Virgilian limestones has an ample supply of quartz silt to provide material for agglutinization into tests.

LARSEN-METHOD AGE DETERMINATIONS OF 150 ROCKS RANGING IN AGE FROM PRECAMBRIAN THROUGH TERTIARY

Howard W. Jaffe, David Gottfried, and Claude L. Waring
U. S. Geological Survey, Washington, D. C.

More than 200 age determinations of zircon, monazite, and xenotime from 150 igneous rocks of the Tertiary through the Precambrian systems are in good agreement with the geology. These include the following points in geologic time for Paleozoic and younger rocks:

Stock, San Juan Mtns., Colorado	late Miocene	16 million years
Stock, Cerrillos Hills, New Mexico	late Eocene or Oligocene	38 million years
Stock, Tintic district, Utah	early late Eocene	48 million years
Batholith of southern California	early late Cretaceous	105 million years
White Mt. plutonic-volcanic series, New Hampshire	Mississippian (?)	233 million years
Batholith, Katahdin, Maine	Middle to Late Devonian	308 million years
Highlandcroft plutonic series, New Hampshire	Ordovician	388 million years

Ages determined on zircon and monazite from metamorphosed Precambrian granitic rocks may be expected to give either the age of the original crystallization of the rock or possibly the date of the last significant recrystallization. These include the following determinations:

Granite, Mellen, Wisconsin	Keweenawan	580 million years
Granites, syenites, Adirondacks, New York	Algoman	540 to 870 million years
Granite, Iron County, Michigan	Killarney	820 million years
Granite, Dickinson County, Michigan	Algoman	1260 million years
Granite, Bodom, Finland	3rd Series	1460 million years
Gneiss, Dickinson County, Michigan	Laurentian	750 million years
Gneiss, Yamba Lake, N. W. Territories	Archean	2800 million years

MINERAL FACIES IN IRON- AND SILICA-RICH ROCKS

H. L. James and A. L. Howland
U. S. Geological Survey, Menlo Park, Calif; Northwestern University, Evanston, Ill.

Mineral assemblages in the iron- and silica-rich rocks are conveniently described by use of ASFF′ diagrams ($A = \frac{1}{2}Al_2O_3$; $S = SiO_2$; $F = FeO$; $F' = \frac{1}{2}Fe_2O_3$) which permits ready application of the mineralogical phase rule to both sediments and their metamorphosed equivalents.

A major factor that determines stable-phase assemblages in the metamorphosed rocks is the degree of oxidation achieved during the primary processes of sedimentation and diagenesis. This degree of oxidation, or oxidation capacity, remains as a virtually fixed property of the rock during much of metamorphism. In effect, it is a measure of the degree to which ferrous and ferric iron have to be treated as separate components. Stilpnomelane is one of the few minerals whose structure permits wide variation in ferrous-ferric ratio in a single phase—in the chlorite zone of metamorphism strong differences in oxidation state of the primary material are preserved in stilpnomelane laminae less than 1 mm thick. More commonly these differences are reflected in the presence of separate phases, such as siderite and magnetite, that differ in ferrous-ferric ratio.

The occurrence of magnetite and specularite as adjacent layers in iron formation within metamorphic zones as high as that of sillimanite demonstrates that original differences in oxidation state are retained to high metamorphic levels.

THERMODYNAMICS OF DOLOMITE AND Ca-Mg CARBONATE SOLID SOLUTIONS

John C. Jamieson
Department of Geology, University of Chicago, Chicago, Ill.

Dolomite is defined as the end member of two solid-solution series, one a mixing of Ca and Mg in planes perpendicular to the *c* axis with alternate cation planes pure Ca, the other with alternate planes pure Mg. Under this definition it is possible to discuss their equilibrium with a disordered Ca-Mg carbonate solid solution. Formulae for the Gibbs free energy of mixing for each phase are postulated consisting of an ideal entropy of mixing and an asymmetrical heat of mixing. A partial empirical fit to the phase-equilibrium data of Harker and Tuttle at 900°C reproduces that of Goldsmith and Graf within their experimental error between 800°C to 500°C and predicts less than 1 per cent solubility of Mg in calcite at room temperature. The modal disagrees with the data for Mg content greater than 50 per cent and agrees poorly with that on dolomite decomposition with varying CO_2 pressure. However, the form of the free-energy curves is believed correct. With decreasing temperature definite free activation energies are required for $CaCO_3$ and $MgCO_3$ to react to form dolomite plus calcite, analogous to those found in the unmixing of alloys. Thus probably the incomplete or slow reactions found in laboratory work are explained, as well as the great persistence of unstable Mg-rich calcites in nature. For a better understanding of the Ca-Mg carbonate relationships, the degree of order of dolomite solid solutions and the disassociation pressures of Ca-containing magnesite must be obtained.

ANCESTRY OF THE CORALLINE ALGAE

J. Harlan Johnson
Colorado School of Mines, Golden, Colo.

Most of the Recent genera of coralline algae date back to the Late Cretaceous or Early Tertiary. Little is known regarding their ancestry. The view has been generally held that the ancestral stock was to be found in the Paleozoic family Solenoporaceae. The primitive genus *Archaeolithothamnion* was supposed to represent a transitional stage between the Solenoporaceae and the more highly developed recent genera.

It is, therefore, highly interesting to note that some Pennsylvanian algae recently studied show structures much more closely allied to the recent genus *Lithophyllum* than any known among the Solenoporaceae. These structures include well-defined hypothallic and perithallic tissues, a co-axial hypothallus, and conceptacles of sporangia.

Other recent finds from Lower Pennsylvanian limestones include abundant debris of a form having structural features suggestive of articulated coralline algae.

It is suggested that the separation of the two types of coralline algae (the crustose and the articulated) may date back to Paleozoic times, and that the two main groups of the crustose corallines (*Lithothamnion* type and *Lithophyllum* type are equally ancient.

LATE PLEISTOCENE AND RECENT GLACIAL CHRONOLOGY OF SOUTH-CENTRAL ALASKA

Thor N. V. Karlstrom
U. S. Geological Survey, Washington, D. C.

A chronology of more than 35 late Pleistocene and Recent glacial events is derived from data obtained in Cook Inlet region, Alaska. Twenty-five radiocarbon age determinations fix time bound-

aries for important stratigraphically recorded events. The Alaskan sequence correlates closely with the radiocarbon-dated North American continental chronology and European late- and post-Glacial chronologies as dated from the Scandinavian varve sequence and from archaeological and historical records. These correlations substantiate parallel climatic histories and argue for acceptance of properly evaluated radiocarbon dates in a near-absolute as well as relative sense.

Eleven glaciations, most with recognizable subdivisions, are named and dated. The ages and presumed continental Pleistocene and Recent correlatives of the Alaskan glaciations are: Recent glaciations beginning 1500 A.D., 500 A.D., and 3500 B.C. ("little ice age"); Wisconsin glaciations beginning 7000 B.C. (Cochrane), 10,500 B.C. (Mankato), 13,500 B.C. (Cary), 17,000 B.C. (Tazewell) and before 35,000 B.C. (Farmdale-Iowan); and pre-Wisconsin glaciations with maxima centered about 60,000–70,000 B.C. (pre-Farmdale, post-Illinoian), and about 100,000–200,000 B.C. (Illinoian). The 4500 to 3000 B.C. interval reflects "Climatic Optimum" conditions.

Graphic comparisons of glacial and postulated extra-terrestrial climatic control curves suggest that stage-rank glacial events reflect the 41,000-year "Obliquity Cycle", and substage and lesser-rank events, cycles of about 3400, 1100, and 550 years which may be related to Pettersson's celestial mechanics tide-generating force curve. Changes in solar output, as represented by the sunspot cycle, appear to be subordinate to other astronomic factors in determining the recorded glaciations.

RADIOCARBON DATING OF THE "COCHRANE READVANCE" IN CANADA

Thor N. V. Karlstrom and Meyer Rubin
U. S. Geological Survey, Washington, D. C.

The precise position of the "Cochrane Readvance" in the Pleistocene continental chronology has long been uncertain. Four radiocarbon samples bearing on the age of the "Cochrane Readvance" were recently dated by the U. S. Geological Survey. Two samples (W-241 and W-242), collected from organic beds underlying surface drift in the Cochrane, Ontario, area, are more than 38,000 years old. Two samples (W-136 and W-176), collected from forest beds near the base and middle of a 4-foot thick peat section overlying glacial lake sediments deposited after ice had retreated north of Cochrane, have ages, consistent with stratigraphic positions, of 6380 $\pm$ 350 and 5300 $\pm$ 300 years BP (Before Present). These results indicate that the Cochrane area may have been under a continuous ice cover from more than 38,000 until some time prior to 6400 years ago, which is in agreement with the radiocarbon results obtained from the Mankato substage (11,000 BP and of pre-Cochrane age) and earlier Wisconsin substages (more than 25,000 to 11,000 years BP). The 6400 minimum date requires that the "Cochrane Readvance" preceded rather than followed the "Climatic Optimum".

New data give a consistent record of a glaciation and eustatic sea-level low between about 9000 and 6500 BP, which appears to correlate with the "Cochrane" as a post-Mankato, pre-"Climatic Optimum" event.

Since numerous radiocarbon dates independently substantiate the European Fennoscandian varve date of 10,800 BP as well as the Fennoscandian-Mankato correlation, the previous correlation of the "Cochrane" with the Fennoscandian appears untenable.

PALEOZOIC OF THE NORTHERN TOQUIMA RANGE, CENTRAL NEVADA

Marshall Kay
Department of Geology, Columbia University, New York, N. Y.

Paleozoic strata of the northern Toquima Range are of two principal facies, a western, the Toquima formation, of chert, siliceous and argillaceous shales, and quartzites, and eastern facies principally of carbonate rocks. The Toquima contains Ordovician graptolites in argillaceous shales and quartzites; folded Toquima beds are overlain unconformably by late Pennsylvanian limestone and lie

structurally thrust on the carbonate sequences. Three distinct carbonate sequences are thrust one on another: the Ordovician Canadian and Chazyan Pogonip formation is the oldest exposed in each (Ikes Canyon section is in the central sequence). In the southeast sequence, the Pogonip is overlain by about 100 feet of Trentonian limestone. The Silurian rocks show greatest contrasts. In the western sequence, several hundred feet of thick-bedded, pure calcitite with corals lies on the Pogonip and forms conspicuous cliffs; in the central sequence, 20 feet or less of similar rock is overlain by several hundred feet of graptolite-bearing shales, and by coralline and brachiopod-bearing limestones, the upper beds probably Devonian; in the southeastern carbonate sequence, the Silurian has about 100 feet of calcareous quartz arenite, dolomite, and laminated black chert beneath several hundred feet of calcareous shales and calcite-quartz siltstones.

The Toquima was strongly folded before late Pennsylvanian. Overthrust cherts occur in the Monitor Range, 20 miles east; thrusting is believed pre-Pennsylvanian. Some of the thrusts separating the carbonate sequences were formed after the emplacement of the thrust sheet with Toquima cherts, and there was later tilting and faulting.

COARSE CONGLOMERATES OF THE MIDDLE ORDOVICIAN IN THE SOUTHERN APPALACHIAN VALLEY

John M. Kellberg and Leland F. Grant
Tennessee Valley Authority, 510 Union Building, Knoxville, Tenn.

Conglomerates of Middle Ordovician age have been studied in six areas at approximately the same stratigraphic position along the southeastern margin of the Valley and Ridge province over a distance of 325 miles from Fincastle, Virginia, through eastern Tennessee to northern Georgia.

Pebbles and cobbles from practically all the older Paleozoic sedimentary formations known in the region have been identified in the conglomerates. Most are limestone derived from the Upper Cambrian and Lower Ordovician, but an appreciable amount of quartzite, sandstone, and siltstone from the Middle and Lower Cambrian sedimentary rocks is present.

Studies of the rounding of the pebbles and cobbles and of the distribution of the coarser beds show that the source area lay to the southeast. These conglomerates are interpreted as representing deposits laid down in a subsiding trough near points of discharge of major streams draining recently uplifted highlands to the southeast. The conglomerates record an early pulsation of the orogenic disturbance which affected the southern Appalachians from Chazy to early Trenton time and which was responsible for the origin of the wedge of clastic rocks of Middle Ordovician age in this region.

TECTONIC HISTORY OF THE COLORADO PLATEAU

Vincent C. Kelley
Department of Geology, University of New Mexico, Albuquerque, N. M.

The earliest tectonic events which appear to have influenced the present structure of the Plateau occurred during Pennsylvanian and Permian times. Three northwesterly trending Permo-Pennsylvanian positives developed on and adjoining the Plateau. These are from north to south the Front Range, Uncompahgre, and Zuni. All appear to have been asymmetrical to the southwest where they were adjoined in order by the Colorado, Paradox, and St. Johns sags.

During Triassic and Jurassic times only broad, slight, epeirogenic sagging occurred between the previous Uncompahgre and Zuni positives. However, during middle and late Triassic times some sharp local flexing occurred in and adjacent to the Pennsylvanian Paradox basin. In late Jurassic time the southern rim of the Plateau was generally tilted northward, and the Cordilleran geanticline west of the Plateau experienced deformations which prefaced the more pronounced orogenies of Cretaceous time. During late Cretaceous time the Plateau was markedly depressed and tilted northward as it became part of the site of the Rocky Mountain geosyncline.

Nearly all the present tectonic features of the Plateau were formed in Laramide time. These consist of seven basins, nine principal uplifts, and many intermediate tectonic divisions such as platforms, slopes, sags, and broad saddles. Long monoclinal flexes between the uplifts and basins were the principal lines of deformation. The Plateau tectonics are closely related to the surrounding orogenic belts, and the Plateau may be divided into western and eastern parts that appear to have deformed somewhat differently in direction and magnitude.

PYROPHYLLITE-SILLIMANITE-MULLITE EQUILIBRIUM RELATIONS TO 20,000 BARS AND 800°C

George C. Kennedy
Institute of Geophysics, University of California, Los Angeles, Calif.

The distinction between mullite and sillimanite can be made readily by x-ray methods. A solid-solution relationship between the two phases exists, and a series of phases ranging in x-ray pattern from mullite to sillimanite has been made.

Pyrophyllite has been heated to 800°C with water pressures up to 20,000 bars. At 150 bars pressure and 500°C, pyrophyllite breaks down to mullite. At 450 bars pressure the reaction pyrophyllite to mullite takes place at 550°C. At 600° and 2000 bars water pressure pyrophyllite breaks down to form a mullite-sillimanite solid solution of about two-thirds sillimanite and one-third mullite. At 14,000 bars and 700°C sillimanite, kyanite, and pyrophyllite, are all in equilibrium. A solid-solution series ranging from mullite at low pressures to sillimanite at higher pressures is thus in equilibrium with pyrophyllite along its dehydration boundary. This series appears in the pressure interval of approximately 400 bars to 3000 bars and in the temperature interval 550°C to 600°C.

Kyanite has been synthesized at high confining pressures over this same temperature interval, but at sufficiently low water pressures so that pyrophyllite does not form. The relationships of kyanite to andalusite to sillimanite-mullite are discussed.

GEOLOGICAL OBSERVATIONS FROM THE GENEVA CONFERENCE ON PEACEFUL USES OF ATOMIC ENERGY

Paul F. Kerr
Department of Geology, Columbia University, New York 27, N. Y.

Some 1100 papers were submitted to the United Nations' conference on the peaceful uses of atomic energy held at Geneva, August 8–20, 1955. Among the papers submitted, 95 were especially prepared for the conference on the geological aspects of the natural occurrence of uranium and thorium. While the proceedings of the conference are to be published, and may be in print by the time this abstract appears, several have suggested that a review of more salient features would be of interest to the Society.

Representatives of 12 delegations participated in a panel session on the natural occurrence of uranium and thorium. An opportunity was offered to compare occurrences in different areas on a world-wide basis. Strong emphasis was placed on the conditions of emplacement in vein deposits both in the Belgian Congo and Canada. Important strides have been made in both areas in recent years in the interpretation of the conditions of vein formation. The interpretations of origin and factors involved in structural, mineralogical, and depositional control applicable to the western United States uranium province drew a large part of the attention of the conference. Special attention was devoted to urano-organic types of accumulation. Another subject of general interest concerned the factors involved in the accumulation of detrital thorium deposits.

It is proposed to discuss the conference from the standpoint of contributions to the geology of uranium and thorium.

ROCK WEATHERING IN ENGINEERING GEOLOGY-PROBLEMS AND NEED FOR RESEARCH

George A. Kiersch
6 Molimo Drive, San Francisco, Calif.

Weathering processes either weaken or enhance the engineering and physical properties of rock and soil; ultimate use of the material dictates the significance of this alteration. Conditions controlling the weathering processes and factors affecting the phenomena are widely discussed in the literature. However, the significance of weathering, particularly regarding the engineering and physical properties of rock and soil masses, has received inadequate attention.

Problems of rock and soil weathering invariably confront the geologist dealing with: excavation characteristics and classification; rebound expansion; tunnels; slope stabilization; adequate foundation, groutability, permeability, and ground-water movement; reservoir leakage and silting; and selection of construction materials. To strengthen geological interpretation and "forecasts", further research investigations are needed on the principal types of rock and soil to establish criteria for: (1) determining the rate of weathering processes; (2) recognition of the degree to which weathering has progressed; (3) determining the engineering and physical properties of the material for each stage of alteration; and (4) applying the criteria to a weathered mass and arriving at an appraisal of its engineering and physical properties.

If available, these data would aid planning and construction efficiency, reduce the "risk" inherent to dealing with weathered rock and soil, and eliminate many design changes often necessary after construction begins. Some research investigations along this line are currently under way.

TRACE-ELEMENT EXPLORATION OF MAINE LAKE WATER

M. Dean Kleinkopf
Standard Oil Co. of Calif., Bakersfield, Calif.

Spectrographic determination of trace elements in lake waters was applied as a reconnaissance prospecting method to a remote area containing approximately 20,000 square miles in northern Maine. From this site, poorly prospected because of vegetation and a scarcity of outcrops, and relatively free from water contamination caused by industry, 689 water samples from 467 lakes were analyzed.

Data for 12 elements normally present in trace amounts in natural waters—copper, lead, zinc, silver, tin, nickel, chromium, manganese, molybdenum, vanadium, zirconium, and titanium—were evaluated by studying their variations from lake to lake. Use of element-weight percentage concentrations in evaporated water residue furnished data which were not affected by rates of erosion and changes in amounts of rainfall and runoff. All values for each element, plotted on a base map of Maine, revealed that lakes with higher values formed groupings which represent localities of greater possibility for mineralization. The reliability of these groupings, or anomalies, has been established by correlation with geologic features and by confirmation with known mineralization. The distribution of the anomalies was expounded geochemically using pH data to account for the behavior of the elements in the weathering cycle. One locality in south-central Piscataquis County containing anomalies for eight elements was sampled in more detail. The result was that three limited zones, each of less than 40 square miles, for lead, zinc, silver, and copper mineralization were recommended for more specific studies such as soil analysis.

GEOLOGY OF URANIUM

M. R. Klepper and D. G. Wyant
U. S. Geological Survey, Spokane, Wash.; U. S. Geological Survey, Grand Junction, Colo.

Igneous processes tend to concentrate uranium in late-phase differentiates, notably in pegmatites, small alkalic plutons, and veins or other epigenetic deposits. The concentrations in igneous rocks

are syngenetic. They may be large but are low grade. Veins and other epigenetic deposits associated with igneous rocks are generally small, but some are high grade. Weathering and sedimentary processes may either disperse or concentrate uranium, depending primarily on climate. Some primary uranium-bearing minerals accumulate in placers. Others are dissolved, and the uranium is transported by ground and surface waters from which it may be precipitated in favorable receptors to form epigenetic deposits. Most deposits thus formed are low grade, but some are large. Some uranium in solution reaches the sea and may be extracted to form large, low grade accumulations in phosphorites or black shales. Metamorphic processes may effect concentrations of uranium by converting pre-existing rocks to magma, which subsequently may form uranium-rich differentiates, or by "sweating" uranium out of weakly uraniferous rocks and concentrating it in favorable geologic settings.

Most of the world's important uranium deposits are clustered in a few areas or provinces that may represent uranium-rich portions of an originally inhomogeneous crust. These uranium-rich provinces apparently persist through long periods of geologic time. Within them, some types of uranium-rich rocks and uranium deposits may be relatively short-lived, depending on the geologic history and climate, but as they are destroyed by erosion or metamorphism, others in equilibrium with the prevailing environment may form.

FORBIDDEN *S*- WAVES

Leon Knopoff
Institute of Geophysics, University of California, Los Angeles, Calif.

An experimental observation of a wave identified as *S*- has been made under conditions which, on the basis of geometrical seismic theory, forbid such an occurrence.

The experiment is that of the normal impulsive surface excitation of a plane elastic slab bounded by air. In line with the source and upon the opposite face of the slab a receiver is placed detecting only the normal component of motion. Both normal *P*- and normal *S*- are observed, identified by their travel times.

By symmetry, transverse motions cannot exist; even if they existed, no normal component of motion would be observed. From the theory of elastic-wave propagation, the exact wave form can be computed for this experiment. An *S*- wave is predicted mathematically. A physical explanation of this phenomenon is obtained by considering this situation as a diffraction problem.

Both mathematical and physical reasoning point to the fallacy of associating the transverse, equivoluminal properties of the infinite medium shear wave with the *S*- wave for the case in which boundaries exist, even though these boundaries be remote. Similarly, *P*- waves in the presence of boundaries are not compressional, irrotational, longitudinal waves.

IMMINENT CAPTURE OF THE MISSISSIPPI—THE PROBLEM OF THE ENLARGING ATCHAFALAYA AND ITS CONTROL

Charles R. Kolb
Waterways Experiment Station, Vicksburg, Miss.

The most significant geological development along the lower Mississippi River in the past century has been the gradual enlargement of its major distributary, the Atchafalaya, from a small bayou to a major river taking more than one-quarter of the flow of the master stream. It is enlarging at the rate of approximately 1 per cent of the main stream discharge each year. Its delta is being built into Grand Lake, 15 miles inland from the Gulf, and deltaic deposits are gradually filling the lake. More than 60 square miles of new land surface has been created since 1932. Studies indicate that, if not artificially controlled, the Atchafalaya will continue to enlarge and will reach a critical stage in its development during the period 1965–1975 when it will carry an estimated 40 per cent of the Mississippi discharge. At that time the diversion process will be greatly accelerated, and capture of the Mississippi will follow.

The diversion follows the pattern of former changes in course of the Mississippi recorded on the alluvial plain. The Atchafalaya meets the two basic requirements for diversion: it furnishes a shorter path to the sea, and it is capable of carrying low-water flow. Factors controlling the rate of diversion include the frequency of floods, the resistance to erosion of bed and bank materials of the diversion arm, and the establishment of a single diversion channel capable of carrying sedimentary load to the sea.

MICROFLORA INVESTIGATIONS IN TERTIARY AND MESOZOIC STRATA OF EUROPE, ESPECIALLY OF GERMANY

Gerhard O. W. Kremp
Department of Geology, Pennsylvania State University, University Park, Pa.

A close similarity has been shown between the microflora of Europe and North America in Tertiary age, and apparently in the Mesozoic too. Therefore, the experience in palynological work gained in Europe, especially in Germany, during the last 25 years may be helpful to American workers.

About 1930 R. Potonie divided the Tertiary of Middle Europe into three parts by the use of microflora. The extensive investigations performed later showed that the change of flora caused by evolution and extinction was very slight, at least since Middle Tertiary time; and plant migration caused by change in climate was very slow and gradual. Thus, we are unable today to distinguish many more subdivisions than those designated by Potonie.

In spite of the generally slow change of floral development in the Tertiary, it was possible to get good results in stratigraphic work by correlating formations, coal seams, and different layers of coal seams. For example, with the help of spore diagnosis, the coal seam from Niederhein which is normally 270 feet thick can be divided into three divisions with eight subdivisions. These subdivisions are recognizable in bore holes over an area of many miles.

These results became available only by an understanding of the recognizable microfloristic factors which indicate different fossil plant associations in different horizons of a coal seam.

POTASH-FELDSPAR EXSOLUTION IN A TERTIARY PORPHYRY*

Frederick J. Kuellmer
New Mexico Bureau of Mines and Mineral Resources, Socorro, N. M.

Near Hillsboro, New Mexico, a funnel-shaped Tertiary (?) quartz monzonite porphyry containing large orthoclase cryptoperthite phenocrysts has intruded early Tertiary (?) andesitic volcanics. Average composition of the cryptoperthites is Or_{75} (Ab + An)$_{25}$($\pm$5 weight %). Compositional ranges of the unmixed phases, in all specimens, and relative to each other, barely exceed the precision of the data. Cryptoperthite homogenization with short heat treatment, and predominant monoclinic symmetry suggest that the cryptoperthites are closer to sanidine than to microcline.

"O/A", the quantity used as a measure of the exsolution, is defined:

$$\frac{\text{Peak height of the } (\bar{2}01) \text{ spacing of the orthoclase-rich phase}}{\text{Peak height of the } (\bar{2}01) \text{ spacing of the albite-rich phase}}.$$

Cryptoperthites heated for 1 hour to 400°–900°C show no pronounced O/A change below 500°C. From 600° to 900°C the log O/A increases linearly with the heating temperature. Thus, higher O/A values for similar compositions appear to correspond to higher-temperature, metastable, inequilibrium states. The O/A ratios for natural cryptoperthites (composition: Or_{66}-Or_{70}) plotted on the geologic map show a general trend from high O/A values in the southwest (interpreted as higher in the igneous intrusive) to lower values in the northeast (a lower horizon in the igneous intrusive). Plotting all O/A values (composition: Or_{60}-Or_{87}) on the map emphasizes the same trend and suggests a possible relationship between sulfide mineralization and O/A ratios.

* Publication authorized by the Director, New Mexico Bureau of Mines and Mineral Resources

Similar approaches to a quantitative evaluation of cryptoperthites may provide significant new data concerning the thermal history of many igneous masses.

SUBSOLIDUS PHASE RELATIONSHIPS IN PART OF THE FeS—Ni-S SYSTEM

Gunnar Kullerud
Geophysical Laboratory, 2801 Upton St., N.W., Washington, D. C.

The subsolidus phase relationships in a part of the Fe—Ni—S system have been studied experimentally. All runs were made in evacuated, closed silica tubing. A section through part of the ternary system at 500° C. shows complete miscibility between Fe_7S_8 and $Ni_{12}S_{13}$ above 396° C. Above this temperature NiS and the $Ni_{1-x}S$ omission solid-solution series have the NiAs structure and therefore are isostructural with the pyrrhotite solid-solution series. At the same temperature about 20 mol per cent NiS is soluble in FeS, and about 30 mol per cent FeS will dissolve in NiS. These solubilities increase markedly with increasing temperature. Mixtures of FeS and NiS containing 20 mol per cent $<$ NiS $<$ 70 mol per cent will when heated at 500° C. for a minimum of 60 days produce both pentlandite and pyrrhotite type $(Fe, Ni)_{1-x}S$ mix crystals. The pentlandite cubic structure tolerates a considerable variation in the Fe to Ni ratio with deflections on both sides of the 1 to 1 ratio.

A cut was made through the ternary system keeping the Fe to Ni ratio equal to 1. In this section the phase-equilibrium diagram for a change in metal to sulfur ratio of 7.5/8 to 9/8 was determined. This phase diagram shows a eutectic at 845° $\pm$ 5° C. and at a metal to sulfur ratio of 7.95/8. The pyrrhotite type mix crystals in this diagram require an increasing amount of sulfur with decreasing temperature. On the other side pentlandite mix crystals require a slight increase in metal content with decreasing temperature. The two diagrams together show that the two-phase (pentlandite and pyrrhotite) field has the shape of an elongated dome. The top of the dome is truncated at atmospheric pressure because the dome and liquidus planes intersect. At high pressure the solidus surfaces may be sufficiently increased to allow a complete series of solid solutions to exist between FeS and NiS.

ZIRCON IN TONALITE, PRIEST LAKE, IDAHO

Leonard H. Larsen
Department of Geology, Columbia University, New York, N. Y.

A 5-pound sample of medium-grained, nonporphyritic tonalite from the Kaniksu batholith was used in this study. Examination of five thin sections shows that zircon occurs as intergranular crystals and as inclusions in all major minerals. However, it is preferentially enclosed in apatite which is usually associated with biotite. A large proportion of the zircons have unusually high elongations. Multiple fracturing across long prismatic zircons show microboudinage structures with rounding of the broken ends.

The rock was crushed to approximately its own grain size, and fractions of the main minerals separated. Zircon concentrates were obtained from each fraction by further crushing and separation. Lengths and breadths of as many zircons as possible were measured for each of the concentrates.

The presence of zircon in all the main minerals indicates that its crystallization is early. The dimensional similarity of zircons concentrated from each of the main minerals further shows that there were no subsequent generations of zircon. The preferred association of zircon with apatite probably indicates that this mineral used zircon as nuclei for crystallization.

STATISTICAL ANALYSIS OF ZIRCONS IN ROCKS

Leonard H. Larsen and Arie Poldervaart
Department of Geology, Columbia University, New York, N. Y.

Measurement of lengths and breadths of 200 zircons separated from a rock is selected as the most satisfactory quantitative basis to characterize a sample by its zircons. Other features of zircons are not so adaptable to exact measurement and standardization.

Frequency-distribution diagrams of length, breadth, and elongation of zircons are useful visual devices for comparison of zircon populations of different rocks.

A new technique is introduced which employs scatter diagrams with length and breadth plotted as independent variables. Thus each zircon is represented by a point on the scatter diagram. A straight line, the reduced major axis, can be calculated which characterizes the distribution of 200 points for each sample. Zircon populations of a large number of samples can be compared readily by plotting their reduced major axes in one diagram.

Each zircon population is represented by five parameters: mean of length, standard deviation of length, mean of breadth, standard deviation of breadth, and slope of the reduced major axis. Rigorous statistical tests may be made for comparison of zircon populations.

QUATERNARY GEOLOGY OF THE CENTRAL GULF COASTAL PLAIN

Rufus J. LeBlanc
Shell Development Company, 3737 Bellaire Blvd., Houston, Texas

The Quaternary of the central Gulf coastal plain consists of five similar depositional sequences, one of which is beneath the present coastal marshland and stream flood plain; each of the other four underlies an uplifted coastal-plain surface and equivalent inland stream terrace. Each sequence consists of a substratum of sands and gravels and a topstratum of sands, silts, and clays, and rests unconformably upon a deeply eroded and weathered surface. Thus, five erosional and depositional cycles reflect fluctuations in sea level which are correlated with five major glacial and interglacial stages. Terrace deposits have been traced northward to the head of the lower Mississippi alluvial valley at Cairo, Illinois. They overlap strata as old as Paleozoic and as young as Pliocene(?) and include fossils of Quaternary age which have been found at numerous surface and subsurface localities.

Structural relationships show progressive sinking of the Gulf Coast geosyncline and inland uplift throughout the Quaternary. Terraces are tilted toward the geosyncline; the oldest (highest) terrace exhibits the steepest seaward slope. Depositional sequences underlying the fluviatile terraces and the Mississippi flood plain reach an average maximum thickness of 250 feet; each thickens abruptly beneath its equivalent coastwise plain. Basal gravels of the oldest terrace have been traced from the outcrop downdip to the New Orleans area where they occur at a depth of nearly 3500 feet in the geosyncline. The Quaternary mass probably reaches its greatest thickness beneath the Continental Shelf where the Plio-Pleistocene boundary is less well defined.

PERMAFROST NEAR LAKE ATHABASKA, SASKATCHEWAN, CANADA

Robert F. Legget
Division of Building Research, National Research Council, Ottawa, Canada

Engineering operations in the Beaverlodge area on the north shore of Lake Athabaska, Saskatchewan, related to the uranium mines have disclosed sporadic permafrost. Maximum depth of frozen ground appears to be about 25 feet so that this location must be close to the southern boundary of permafrost at this longitude. The usual phenomena are observed when the vegetal cover over the permafrost is disturbed. Sharp-faced boulder-sized holes are found in the frozen silt the origin of which is thought to be the melting of small blocks of ground ice. Observations of soil-temperature variations in this area confirm the probability of local ground ice, the melting of which is discussed in relation to ice-melt depressions in general. The observations recorded are part of a continuing survey of the southern boundary of permafrost in Canada being carried out by the Division of Building Research of the (Canadian) National Research Council.

PRELIMINARY INVESTIGATIONS OF ROCK CONDUCTIVITY AND TERRESTRIAL HEAT FLOW IN SOUTHEASTERN MICHIGAN

Geo. W. Leney and James T. Wilson
Dept. of Geology, University of Michigan, Ann Arbor, Mich.

A preliminary measurement of terrestrial heat flow for southeastern Michigan is 0.8×10^{-6} cal/cm²/sec. This value is based on the measurement of conductivity of 13 specimens from the section above and including the Salina Salt formation of Silurian age, and on temperature measurements made in the International Salt Company mine in Melvindale, Michigan, and in one bore hole at Detroit-Wayne Major Airport. Conductivities were measured by a variation of the "divided-bar" technique; mine and bore-hole temperatures were measured with a thermistor and Wheatstone bridge.

INTERRELATION OF RIVER CHANNEL PATTERNS BRAIDED, MEANDERING, AND STRAIGHT*

Luna B. Leopold
U. S. Geological Survey, Washington, D. C.

Natural channels characteristically exhibit alternating deep and shallow sections called pools and riffles. This alternation occurs in all channel patterns whether meandering, braided, or straight. The length of the pool or distance between successive riffles in a straight channel equals the straight-line distance between successive points of inflection in a meandering river of the same discharge. The shallow sections in a meander correspond to riffles in the straight channel.

The distance between riffles, equal to half the wave length of the meander, varies as a linear function of channel width. The meander wave length is approximately 10 times the channel width regardless of the size of the river.

Meandering and braided streams respectively have characteristic combinations of values of slope and bankfull discharge. At a given discharge, a change from meandering to braided is accompanied by increase of slope. At a given slope, braided channels are associated with a greater discharge than meandering ones.

The hydraulic characteristics of channels of different patterns exhibit a spectrum or continuum within which braided, meandering, and straight channels intergrade.

ALTERATION NEAR AN ACID HALOGEN-SULFUR FUMAROLE

T. S. Lovering
U. S. Geological Survey, Denver, Colorado

A series of specimens of ash and pumice, collected outward from the throat of Fumarole No. 1 of Zies in The Valley of Ten Thousand Smokes in 1952, has been analyzed for major and minor constituents. The bulk density—approximately 1.00 for unaltered ash—was determined by weighing blocks of known volume, and chemical addition or subtraction was calculated for unit volume. Elements readily converted to volatile fluorides or chlorides were leached near the hot throat, but hydrolysis resulted in some late-stage addition in the innermost zone. Condensation of steam and inward movement of hot acid water resulted in outer zones of oxidation and leaching, with an intermediate zone of boiling and evaporation, which was especially enriched in alumina and water of hydration.

Appreciable quantities of Pb, Zn, Cu, As, Cl, F, and SO_4 were added to the innermost zone (1

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inch), and Ni, Co, B, and Sc were concentrated in the intermediate zone about 2 feet from the throat. No carbonate is present in any zone.

Magnetite, hematite, goethite, hydromica, opal, montmorillonite, and kaolinite are the chief alteration minerals. The alteration is similar to that produced by strong sulfur acids elsewhere, but the gas of fumarole No. 1 contained only 7 ppm S in 1917 and 70 ppm in 1919. In contrast it carried 240 ppm in HCl and 30 ppm HF in 1917—the only year in which samples of halogen gases were collected in the Valley.

EVOLUTION OF STREAM VALLEYS IN SOUTHWESTERN MONTANA

Wayne Russell Lowell
Department of Geology, Indiana University, Bloomington, Ind.

Many large valleys in southwestern Montana, such as Jefferson and Big Hole valleys, were formed about early Eocene time and were either structural basins or stream valleys. The present valleys contain remnants of nearly horizontal Tertiary "lake beds", as old as Eocene, at or near the present floors. The "lake beds" abut against deformed Paleozoic and Mesozoic rocks of the valley slopes. Rivers draining the present valleys flow through canyons cut across geologic structures. The canyons were formed by streams superposed from the "lake beds".

Jefferson Canyon has been eroded into a resistant mass of Paleozoic rocks that is surrounded by "lake beds". Extensive "lake beds" of Oligocene to Pliocene age are found on both sides of the Jefferson River near Cardwell at an elevation of 4400 feet, and remnants of "lake beds" are found at 5600 feet elevation on Paleozoic rocks north of the canyon. The evidence suggests that the Paleozoic mass was buried by "lake beds" and that the river was superposed onto the Paleozoic rocks.

The Big Hole River, in the Melrose area, follows a canyon cut 1200 feet into deformed Paleozoic and Mesozoic rocks. East of this canyon, an earlier stream valley had been filled with poorly consolidated gravels that would provide an easier route for the river. The modern course of the Big Hole River resulted from a meandering predecessor that was superimposed onto the older rocks.

Similar evidence in other valleys indicates that they were formed in early Tertiary time, were filled with sediments, and today are being exhumed.

DON'T PENALIZE THE POTENTIAL GEOLOGY MAJOR

John B. Lucke
University of Connecticut, Storrs, Conn.

General education is today's antidote for the abuses of the free election system of a generation ago. One of its devices is to substitute for traditional "content" subjects broad synthesis or "survey" courses occupying as much as half the class time of underclassmen, in many colleges. The effect on our profession is crippling; fewer geology majors with poorer academic grounding are available, in the face of rising demand for geologists and more rigorous training for them.

College geology shares with physics, chemistry, and biology the dual obligation of educating youth to think and also of providing pre-professional training. Unlike its "rivals", geology seldom enjoys a head start in secondary schools, and a thorough grounding in all these sister sciences is basic to the properly prepared geology major.

According to professional geologists, the ideal major should take at least one year of college chemistry, physics, mathematics, and biology as well as English, engineering, and a foreign language. However, the typical potential major is an underclassman with an open mind who doesn't know what he wants to do. If excited by the introductory course, he decides to major in geology perhaps late in sophomore year. He rarely has time for all the "basic" courses even if he does not take advanced R.O.T.C. He is seriously penalized if his early years were occupied with survey courses to the exclusion of more traditional-content courses. The trend toward survey courses should be reversed to afford the potential geology major broader choice.

CALCITE-ARAGONITE EQUILIBRIUM RELATIONS AT ELEVATED PRESSURE AND TEMPERATURES

Gordon J. F. MacDonald
Institute of Geophysics, University of California, Los Angeles 24, Calif.

The calcite-aragonite equilibrium relations have been investigated using the high-pressure apparatus described by Griggs, Fyfe, and Kennedy. Samples of natural calcite and synthetic aragonite were subjected to pressures up to 30,000 bars in the temperature range 200°C to 600°C. The equilibrium curve as determined by this study is given by the equation $P = 17T - 2{,}700$ where P is in bars and T is in degrees absolute. Calcite inverts to aragonite at pressures greater than those given by this equation. The inversion is reversible with aragonite converting to calcite at higher temperature. The estimated uncertainty in the position of the equilibrium curve is 10 per cent of the pressure. These results are in agreement with the thermochemical study of the equilibrium relations made by Jamieson.

The calcite-aragonite equilibrium curve is of importance to petrology since it fixes an upper limit of pressure to which calcite marbles have been subjected during metamorphism.

CRYSTALLINE MODIFICATION OF $NaAlSi_2O_5$

W. S. MacKenzie and J. R. Smith
Geophysical Laboratory, 2801 Upton St., N.W., Washington, D. C.

Heating of natural low-temperature albite causes apparently continuous changes in its x-ray powder pattern to that characteristic of the high-temperature form; optical examination and single-crystal x-ray photographs of albite partly inverted from the low to the high form reveal the presence of two discrete phases.

The lattice parameters of albite synthesized in the presence of water vapor vary according to the conditions of crystallization. The important factors controlling these variations are: (1) temperature of crystallization, (2) period of crystallization, and (3) pressure of water vapor. The value of $2\theta_{131} - 2\theta_{1\bar{3}1}$ is sensitive to the variations in the lattice parameters; $2\theta_{131} - 2\theta_{1\bar{3}1}$ for low albite is about 1.07° (filtered Cu radiation) and for high albite is about 2.01°. The lowest value of $2\theta_{131} - 2\theta_{1\bar{3}1}$ obtained for a synthetic albite is 1.729° for albite crystallized at 600° C., P_{H_2O} = 51,000 p.s.i. for a period of 823 hours.

The results suggest that, in the stability field of the low-temperature form, high-temperature albite may crystallize metastably but that over a long period of time it will invert to the stable low-temperature form.

RELATIONSHIP BETWEEN DEFORMATION AND IGNEOUS ACTIVITY IN THE COLORADO PLATEAU-BASIN RANGE TRANSITION ZONE IN SOUTHWESTERN UTAH

J. Hoover Mackin
U. S. Geological Survey, University of Washington, Seattle, Wash.

Laramide orogeny is represented in the Cedar City-Iron Springs area by two anticlines of the foreland type. The western limb of each is thrust eastward over an inverted eastern limb. The folds involve strata of late Cretaceous age, and the deformed strata are overlain unconformably by the Claron formation of latest Cretaceous or early Tertiary age.

Igneous activity began late in Claron time. A sequence of volcanic rocks, chiefly latitic ignimbrites with an aggregate thickness of 3000 feet, rests conformably on the Claron. Laccoliths of quartz monzonite porphyry were emplaced during the period of ignimbrite vulcanism. The beginning of the igneous activity was separated from the Laramide folding by an interval long enough for erosional truncation of the folds and deposition of 1000 feet of nonvolcanic Claron strata on the erosion surface.

The Claron formation and early (pre-intrusive) members of the ignimbrite sequence are overturned and thrust radially outward around the borders of some of the laccoliths. Pattern relationships prove that this deformation was due wholly to intrusion; there is no evidence of regional tectonism at the time of intrusion.

Outward for several miles from near-vertical parts of the laccolith border zones the Claron formation and pre-intrusive members of the ignimbrite sequence are in some places involved in chaotic structures of several types. These structures override little-deformed rocks and are locally overlapped by post-intrusive ignimbrites. Field relations indicate that the chaotic structures were formed by landsliding from the steep flanks of the intrusive domes.

PHOTOMETER METHOD FOR DETERMINING QUARTZ-GRAIN ORIENTATION

Joseph D. Martinez
Humble Oil & Refining Company, P.O. Box 2180, Houston, Texas

A new method is described for determining the direction and relative degree of preferential quartz-grain orientation in rocks principally composed of quartz. It is intended primarily as a tool for studying the depositional fabric in sandstones. Older methods involved observation of many individual grains, and in order to sample the unit properly many tedious and time-consuming measurements had to be made. A few simple observations utilizing this new method result in a determination of the integrated effect of hundreds, and in many cases thousands, of grains.

The technique consists of measuring with an attached photometer the variation in the intensity of monochromatic light passed through a standard thin section of sandstone on the stage of a petrographic microscope with gypsum plate inserted and nicols crossed, during a 360-degree rotation of the stage. Minimum intensity of light occurs when the trend of the optic axes of the quartz grains parallels the slow direction of vibration of light in the gypsum plate. Experimental data establish the fact that the trend of the elongate axes of the quartz grains also lies parallel to this direction of vibration.

A petrofabric study, utilizing this method, was made of a sandstone from the Bell Canyon formation, outcropping in the vicinity of the El Capitan Reef Escarpment, near Nickel in Culberson County, Texas. Results of this study are compared with the direction of alignment of oriented fusulinids and the trend of ripple marks in this formation.

METAMORPHISM IN THE LLANORIA STRUCTURAL BELT

P. H. Masson
Humble Oil & Refining Company, P.O. Box 2180, Houston, Texas

The subsurface belt of deformed rocks which extends from the Ouachita Mountains to the Marathon Uplift in Trans-Pecos Texas is characterized by weak progressive regional metamorphism which increases in intensity eastward and southward. To determine details of structural trends and patterns of metamorphism, thin sections of samples from 240 wells along the belt were examined, and the degree of metamorphism in each was established. Excepting biotite schists in two wells, all known metamorphism is within the lower subfacies of the greenschist facies. Criteria for recognition of five ranks of progressive regional metamorphism were established on the basis of textural changes alone. Metasediments in parallel zones of semislate, slate, phyllite, fine-grained schist, and schist make up the inner flank of the structural belt. The schist zones are discontinuous and form several higher-rank nodes along the metamorphic axis. The Gulfward flank is not reached in wells, and outlines of these nodes cannot be completed. The metamorphic axis is continuous on the north with the axis of late Paleozoic metamorphism in the Ouachita Mountains, but continuity at the southwest end of the belt is less obvious. The westernmost segment of the belt contains meta-igneous rocks which may belong with Precambrian rocks exposed in the Van Horn region. This and other lithologic dissimilarities plus gravity data suggest that the main belt diverges from this western segment and extends southeast across the Rio Grande into Mexico.

DETERMINATION OF RANDOM INTERSTRATIFICATION IN MONTMORILLONITE

J. L. McAtee, Jr.
Baroid Division, National Lead Company, Box 1675, Houston, Texas

In the study of clay minerals, x-ray diffraction patterns are often obtained for samples which are not pure minerals but are mixtures in which layers of different types alternate. There are three types of interstratification: (1) random, (2) regular, (3) segregated into zones in the individual crystallites. The usual method of determining the degree and type of random interstratification is by the method of Hendricks and Teller by which theoretical scattering curves are constructed for the various mixtures. The method presented here is a Fourier transform method which can be used to calculate the degree and type of interstratification directly from the measured x-ray data.

Fourier transforms have been calculated for a series of sodium-calcium montmorillonites from 100% sodium and 0% calcium to 0% sodium and 100% calcium. Intensities of the various Fourier peaks give a good representation of the type of random interstratification in the samples. The intensities are also related to the amount of monovalent and divalent ions. Therefore, by using the experimental x-ray diffraction data alone, one can estimate the degree and type of random interstratifications in montmorillonite.

FOUNDATION CHARACTERISTICS OF LATE QUATERNARY CLAYS OFFSHORE NEAR MODERN MISSISSIPPI DELTA

Bramlette McClelland
2649 North Main, Houston, Texas

Studies at oil-well drilling sites in the Gulf of Mexico have revealed shear-strength variations from 2000 pounds per square foot to less than 16 pounds per square foot for soils at the mud line. Penetration of bearing piles supporting existing structures ranges from 15 to 380 feet below the mud line. Delineation of such variations, by areas, would be desirable. To accomplish this, scarce boring information must be extended by geologic interpretation.

Strength of water-deposited clays varies directly with pre-consolidation pressure (the highest intergranular pressure which the soil has experienced). Pre-consolidation pressure can be less than the total submerged weight of overlying soil (when overburden includes very young deposits) and sometimes more than overburden weight (if erosion has occurred). Test data indicate a ratio of shear strength to pre-consolidation pressure of 0.15 for Recent pro-delta deposits of the Mississippi River.

Study of strength versus depth profiles at various offshore points near the modern Mississippi delta indicates: (1) deposition near mouth of Southwest Pass is so recent that pre-consolidation pressures and soil strengths are negligible to 140-foot depth; (2) clay deposits 10 miles offshore southwest of Venice are normally consolidated, verifying greater age of these deposits relative to those last mentioned; and (3) erosion has removed 30 feet of soil in Bay Marchand area. Similar strength patterns should exist in areas where clays of comparable age were deposited in comparable environments, as revealed by geologic studies of delta formation.

RADIOCARBON DATING OF THE LATE QUATERNARY IN SOUTHERN LOUISIANA

E. McFarlan, Jr.
Humble Oil & Refining Company, P.O. Box 2180, Houston, Texas

Deposits of the middle and late phases of the Late Quaternary cycle in Louisiana have been dated by radiocarbon analyses. The early phase, associated with the lowering of sea level, is too old to be measured by this method; a minimum age for its completion is, however, indicated by the

fact that wood samples associated with the weathered zone of the Mississippi entrenched valley system are more than 30,000 years old. Marine shells 100 feet above the base of the Middle phase deposits are approximately 21,000 years old, but no sample has been obtained which could be used to date the beginning of that phase when the sea first began to rise.

Analyses of both wood and shell samples from beneath the Mississippi deltaic plain and adjacent portions of the Continental Shelf indicate that the sea had risen to within 100 feet of its present level approximately 10,000 years ago. They also show that the late phase of the cycle, the epoch of standing sea level, began approximately 5000 years ago. However, the Mississippi deltaic plain and the chenier plain of southwest Louisiana have developed during the late phase. The oldest beach ridge in the chenier plain is approximately 3000 years old, and the oldest distributary system which has been dated is approximately 4000 years old. The river course at New Orleans was established approximately 1000 years ago, and the modern birdfoot delta began to develop approximately 500 years ago.

CORRELATION OF PREHISTORIC SETTLEMENTS AND DELTA DEVELOPMENT

William G. McIntire and James P. Morgan
School of Geology, Louisiana State University, Baton Rouge, La.

Man has lived in Coastal Louisiana for more than 2000 years. During this part of the Recent the Mississippi River has shifted its delta several times and each time provided new areas suitable for human occupation. The home sites of early man, represented by Indian mounds and middens, are concentrated along the habitable portions of the delta—namely, stream levees and beach ridges. As pottery fragments, or potsherds, are the only universal cultural remains that have withstood both time and the elements, they have been systematically gathered and classified from more than 500 sites in the deltaic and marginal deltaic areas of Coastal Louisiana. The pottery markings and designs have gradually changed throughout the 2000 years, and it is through measurements of these changes that a sequence of archeological periods has been developed. By mapping the distribution of dwelling sites through each of five archeological periods it is possible to relate archeological sequence to river and delta sequence. The initial occupation of each site then gives a minimum archeological dating for the physiographic feature, natural levee or beach ridge, upon which that site is located. Initial occupation maps, therefore, give a sequence of relative datings which can be used for deciphering deltaic changes during the last 2000 years. Carbon-14 datings are being employed to verify the relative archeological dates as well as give maximum dates for the various delta masses on which the sites are located.

CARBONATE BANK DEPOSITS IN THE DEVONIAN OF THE ALBERTA ROCKY MOUNTAINS, CANADA*

D. J. McLaren
Geological Survey of Canada, Ottawa, Canada

The upper part of the Upper Devonian Fairholme group in areas of carbonate development in the Alberta Rockies consists of a complex of limestones and dolomites. Among these, gray and light-gray massive and thick-bedded rocks, featureless in the field, show interesting variation in thin section. In the limestones four main lithologic types are recognized: (1) "cabbage-head" stromatolites and irregularly banded rocks, commonly occurring as bioherms, formed of interbanded, recrystallized, and aphanitic limestone commonly with grumelous or "clotted" texture; (2) bioclastics formed of fragments of corals, stromatoporoids, brachiopods, and mollusks, from pebble to silt-

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grade particle size, in clear calcite matrix; (3) medium- to coarse-grained granular rocks formed of rounded to subrounded grains of aphanitic limestone in clear calcite matrix; (4) grumelous or "clotted" textured rocks exhibiting incipient granularity of aphanitic limestone, but without discrete grains. All possible intergradations occur. Calcispheres are common in types 2, 3, and 4. All types may be dolomitized, but structures are preserved as pleochroic shadows independent of the crystal grains of dolomite.

The macrostructure of type 1 may be matched by recent laminated sediments trapped by blue-green algae on emergent mud flats in Florida Bay; of type 2 by beach and shallow-water sands near the fringing Cays of the Bahama Banks; of type 3 by underwater dune sands from the interior of the Bahama Banks as described by Illing. Type 4 is uncertain in origin but is believed to be formed from flocculant muds possibly algal in part.

TIMISKAMING SEDIMENTATION

Dean B. McLaughlin
Observatory, University of Michigan, Ann Arbor, Mich.

The Timiskaming series includes thick graywackes and slates, with cross-bedded arkosites and lenticular conglomerates thousands of feet thick. According to previous hypotheses of origin (Cooke, Pettijohn, Thomson), the graywackes are marine beds, and the conglomerates and arkosites are alluvial fans or piedmont shore deposits. Pettijohn considered the graywackes geosynclinal sediments. Existence of several belts, each with thick conglomerate, is difficult to reconcile with geosynclinal deposition. The suggestion that each belt is of different age would require the additional assumption that a large percentage of conglomerate has been preserved, though much graywacke has been eroded.

The author suggests that the facts are consistent with deposition in intermontane valleys, partly occupied by deep lakes. The graywackes and slates then represent deep lake-bed sediments, the arkosites and conglomerates alluvial fans.

For the origin of the deep valleys the following hypothesis is suggested. Keewatin and pre-Keewatin lavas and sediments were folded and intruded by granites during pre-Timiskaming orogeny, which is attested by angular unconformities at Porcupine and Kirkland Lake. The valleys were then eroded on synclinal belts of weaker lavas and sediments, while the unroofed batholiths formed highlands.

Since the valleys were floored and bordered mainly by Keewatin rocks, the Timiskaming nearly everywhere rests on Keewatin. The highlands, however, supplied abundant detritus, including boulders in the conglomerates. This explains the anomaly that the Timiskaming contains much granite debris, yet is seen resting on granite at very few places.

ARCHIPELAGIC APRONS

Henry W. Menard
U. S. Navy Electronics Laboratory, San Diego, Calif.

Most of the Pacific basin sea floor is hilly, but large-scale echograms indicate areas totaling 5 by 10^6 sq mi (10%) are smooth. The only smooth areas bordering continents are the great Gulf of Alaska plain, the Deep Plain off California, and an apron off Japan, (total area 1.2 by 10^6 sq mi). The remaining smooth areas are distributed as aprons around archipelagoes of islands or seamounts or as plains made up of composite aprons between archipelagoes. These aprons, exclusively associated with islands or ancient islands, are here called archipelagic aprons. In the central and western Pacific, aprons fringe the Hawaiian, Line, Marshall, Caroline, Gilbert, Ellis, Samoan, Cook, Society, and Marquesas islands and the guyots of the Mid-Pacific Mountains, Emperor Seamounts, and the

Magellan Seamounts. The Galapagos and Revillagigedo islands in the eastern Pacific lack extensive aprons.

Archipelagic aprons are remarkably similar. The Marquesas Islands are ringed by a typical smooth, concave-upward, deep-sea channeled apron 140 miles wide. The apron is surrounded by a vast expanse of 1000 to 2000-foot hills. If similar hills are covered by the apron, the minimum volume of the apron is 10–100 times (according to various assumptions) greater than that of the Marquesas volcanoes. Consequently it appears questionable whether the apron was formed by erosion of the volcanoes and whether archipelagic aprons have the same origin as the abyssal plains fringing continents.

SEISMIC STUDIES OF OFFSHORE GEOLOGIC STRUCTURE BETWEEN CHARLESTON, SOUTH CAROLINA, AND CAPE FEAR, NORTH CAROLINA

R. P. Meyer
Dept. of Geology, University of Wisconsin, Madison, Wis.

Ten reverse seismic-refraction profiles were established between the 10- and 20-fms lines off the North Carolina-South Carolina coast. The number of refracting horizons mapped varied from three to five; the crystalline basement rocks show up with characteristic velocities of 16,000 feet/second to 22,000 feet per second. Six profiles were established near the Cape Fear structural axis which in this area constitutes a prominent basement ridge rising from about −4000 feet off Charleston to −2000 feet off Cape Fear and falling away to the north to about −10,000 feet at Cape Hatteras. The ridge strikes approximately perpendicular to the general coast line.

The general seaward slope of the basement rocks increases with distance from the shore. Seismic studies in this area are being continued.

NEW MINERAL, GARRELSITE $(Ba_{.65}\ Ca_{.29}\ Mg_{.06})_4\ H_6Si_2B_6O_{20}$, FROM THE GREEN RIVER FORMATION, UTAH

Charles Milton, J. M. Axelrod, and F. S. Grimaldi
U. S. Geological Survey, Washington, D. C.

Core from the Sun Oil Company South Ouray No. 1 Well, Uintah County, Utah, from 2139 to 2370 feet, contains sparse crystals a few mm long of a new mineral, garrelsite, in brown dolomitic shale containing nahcolite, shortite, searlesite, and (microscopic) wurtzite, but no leucosphenite, reedmergnerite, or eitelite.

Relationship, now under study, is indicated by the formulas of

Datolite $Ca_4B_4(SiO_4)_4(OH)_4$
Bakerite $Ca_4B_4(BO_4)(SiO_4)_2(OH)_2H_2O$
Garrelsite $(Ba,Ca,Mg)_4B_4(BO_4)_2(SiO_4)_2(OH)_2H_2O$

Refractive indices of garrelsite are $\alpha = 1.620$, $\beta = 1.633$, $\gamma = 1.640$ (all $\pm$ .003), γ = b, 2V = 72°. Space group C_s^4 − Aa or C_{2h}^6 − A2/a (monoclinic) with a = 13.43A, b = 8.45A, c = 14.61A, $\beta = 114°19'$, Z = 4, $D_{meas.} = 3.68$, $D_{calc.} = 3.73$. The crystals have a characteristic four-sided steep bipyramidal shape, formed by the prismatic faces (110) and $(1\bar{1}0)$ and the pyramidal faces $(21\bar{1})$ and $(2\bar{1}\bar{1})$. All faces are sharply striated by alternation of prism and pyramid. The colorless crystals are darkened by zoned inclusion of matrix material; but 27 milligrams of relatively clean outer zone was suitable for analysis. Garrelsite is named in honor of Robert M. Garrels, of the Department of Geology at Harvard University, who was Chief, Solid State Group, Geochemistry and Petrology Branch, U. S. Geological Survey, when the mineral was discovered.

RELATION OF PYRITE, PYRRHOTITE, AND MAGNETITE TO REGIONAL AND CONTACT METAMORPHISM IN THE PHILLIPS-RANGELEY REGION, MAINE

Robert H. Moench
U. S. Geological Survey, Box 360, Grand Junction, Colo.

In the Phillips-Rangeley region, Maine, the distribution of pyrite, pyrrhotite, and magnetite in rock units that can be traced from the original sedimentary rocks through low- to middle-grade regional metamorphic rocks into high-grade contact-metamorphic rocks provides a qualitative clue to the importance of partial vapor-pressure variations in regional and contact metamorphism.

Iron sulfides are abundantly disseminated throughout one formation, including black siltstone, shale, marl, and impure limestone; they are locally disseminated in another unit, including arkose and conglomerate. In the northern part of the region these rocks are unmetamorphosed. To the south the rocks are regionally metamorphosed to a low- to middle grade (staurolitic) and are intruded by two plutons, surrounded by sillimanitic halos up to 2 miles wide at the surface.

Cubic pyrite occurs in the unmetamorphosed rocks, and pyrrhotite in the regionally metamorphosed rocks. In the outer parts of the contact-metamorphic halos pyrite and pyrrhotite coexist but replace one another. Near the plutonic contacts the sulfides disappear, and magnetic apparently takes their place.

Inferred processes are:

1. Pyrite developed under closed-basin sedimentation conditions.
2. Pyrite $\rightarrow$ pyrrhotite + sulfur $\uparrow$ during low-grade regional metamorphism; low temperature, pressure, and sulfur vapor partial pressure prevail; pyrrhotite persists through middle-grade.
3. Pyrite $\rightleftharpoons$ pyrrhotite + sulfur near outer margin of halo; moderate temperature and pressure, and relatively high sulfur vapor partial pressure prevail.
4. Sulfur is driven off near plutonic contacts; magnetite possibly forms at the expense of the iron sulfides with some oxidation.

REVERSE FAULTING IN THE COASTAL PLAIN OF ALABAMA

Watson H. Monroe
U. S. Geological Survey, Washington, D. C.

The southwesterly regional dip of the Cretaceous rocks in western Alabama is interrupted by several parallel fault blocks bounded by reverse faults. The fault blocks are long and narrow, and all approximately parallel the regional strike of N. 70° W. Most of the faults dip from 38° to 45°, but a few dip as steeply as 70°, and one dips 8°.

The fault blocks are most abundant north of Livingston in Sumter County, where several may be seen along U. S. Highway 11. Although the individual fault blocks can be traced only 1–2 miles, the zone of faulting extends southeast at least 50 miles to the eastern side of Marengo County.

The faulted belt seems to be related to structural movements in Late Cretaceous and early Paleocene time, which are indicated by marked variations in thickness of several formations. The Ripley formation (Upper Cretaceous) is more than 200 feet thick north of the fault zone but only 35 feet thick just south of the zone. Several other formations show similar local thinning.

No entirely satisfactory explanation for the reverse faults has been found, but the structure may be related to the former northern edge of a large salt basin possibly of Jurassic age.

WRENCH-FAULT TECTONICS

John D. Moody and Melvin J. Hill
Gulf Oil Corp., Fort Worth, Texas; Western Gulf Oil Co., Los Angeles, Calif.

Extending the work of Anderson, Hubbert, and Hafner on faulting, the authors develop the hypothesis that anticlinal folds, thrust faults, and *wrench faults* can result from movement on a large

wrench fault such as the San Andreas of California. This concept indicates that for any tectonic area eight directions of wrench faulting and four directions of anticlinal folding and/or thrusting should accommodate the structural elements. These directions should be roughly symmetrically disposed relative to the direction of the primary compressive stress. The angles α, β, and γ are defined to describe the geometry of such *wrench-fault tectonic systems*.

The authors' interpretations of tectonics in various areas indicate that wrench-fault tectonic systems do exist in nature and are aligned systematically over large portions of the earth's crust as indicated by Hobbs, Vening Meinesz, Sonder, and others. Eight principal wrench directions are defined in terms of major crustal elements such as the Alpine fault of New Zealand. Structural elements aligned in these eight directions constitute major features of Sonder's *regmatic shear pattern*; this shear pattern can have resulted from stresses oriented essentially meridionally, which have been acting in the same direction throughout much of crustal history.

Major wrench faults, which penetrate the earth's outer crust and which result in wholesale segmentation of the crust into polygonal blocks, may constitute the primary type of yielding in the crust.

LIVE FORAMINIFERA FROM CRANE KEY, FLORIDA

Wayne E. Moore
Dept. of Geology, Virginia Polytechnic Institute, Blacksburg, Va.

Laboratory observations indicate that two new species of *Quinquiloculina* are well adapted to their natural environment, a salt pond on Crane Key in Florida Bay, where seasonal evaporation and rainfall cause abrupt and extreme temperature and salinity fluctuations. These species have survived temperatures ranging from 50° to 100°F. Temperatures ranging from 50° to 65°F. were common during the winter. Summer temperatures were normally above 90°F. These Foraminifera survived measured salinities ranging from that of normal sea water to twice that amount. Higher salinities, estimated to be four times that of normal sea water, were maintained for as much as 2 weeks without fatal results. At these high salinities the Foraminifera become inactive, retract their protoplasm, and await the return of more normal salinities. Sudden and extreme changes in salinity do not noticeably disturb these species. From July 29, 1954, until May 4, 1955, the culture was kept in subdued light, and for 5 consecutive months of this time the culture jar was sealed. Algal growth during this time was adequate to maintain the Foraminifera. There is some indication that these miliolids live on the surface of the algae when oxygen is scarce and within the fecal debris on the bottom when oxygen is plentiful.

SOLUBILITY OF SOLIDS IN SUPERHEATED STEAM

George W. Morey
Geophysical Laboratory, 2801 Upton St. N.W., Washington, D. C.

The phenomenon of solids being dissolved by superheated steam at high pressures is an example of the not unusual phenomenon of solubility of solids in gases. The basic concept of a solid dissolved by a gas sounds paradoxical, but its reality has been demonstrated many times by many workers. Ice is soluble in compressed air! The actual values of solubility obtained in our experiments are always much larger than would be predicted from simple theory. Every substance has its own vapor pressure, and elementary principles would suggest that the solubility of an oxide such as quartz or iron oxide would be that corresponding to this partial pressure of the solid, a wholly insignificant amount. A more rigorous treatment would take into account the fact that the high pressure of steam acting on the solid would increase its vapor pressure by an amount which can be calculated from an equation given by Gibbs. This correction, known as the Poynting effect, is small, and in all examples studied the content of the solid material in the gas is many times greater than that predicted by theory. The author has extended his results with quartz to 600° and 45,000 psi, at which

pressure the solubility was 1.1%, a value which lies on the extrapolated curve of his previous results. The following new results have been obtained with water at 15,000 psi: GeO_2: 400°, 0.45%; 550°, 0.88%; 600°, 1.24%. BeO: 400°, 66 ppm; 500°, 120 ppm. NiO: 400°, 20 ppm; 500°, 20 ppm; 600°, 34 ppm. Ta_2O_5: 400°, 9 ppm; 500°, 30 ppm; 600°, 13 ppm. In addition results will be presented obtained with a mixture of 7% CO_2, 93% H_2O at 15,000 psi. These include: $CaCO_3$, 940 ppm; SnO_2, 50 ppm; Fe_2O_3, 230 ppm; quartz, 19×10^{-4}. For quartz this is a decrease of 25%, for $CaCO_3$ an increase of 7-fold; for Fe_2O_3, an increase of 3-fold over the solubility with water alone.

PROBLEMS OF THE IRON-MANGANESE PHOSPHATES

Mary E. Mrose
U. S. Geological Survey, Washington, D. C.

Compilation of optical, single-crystal, and powder data for determinative tables of iron-manganese phosphates led to investigation of several problems.

Dufrenite, andrewsite, and laubmannite are isostructural if, indeed, not the same mineral. Dufrenite has space group $P2_1/n$; $a_0 = 24.6$ Å, $b_0 = 5.14$, $c_0 = 13.87$, $\beta = 100°25'$; specific gravity 3.34 (meas.). Crystals long prismatic.

X-ray data for a yellow-brown mineral, occurring as crystals and sheaflike aggregates with rockbridgeite at the Fletcher and Palermo mines, New Hampshire, agree with those of a mineral on specimens labeled xanthoxenite (Hagendorf): $a_0 = 15.02$ Å, $b_0 = 18.75$, $c_0 = 7.23$. Specific gravity 2.90 (calc.), 2.85 (meas.). Biaxial negative (?), $\alpha = 1.682$ (pale yellow brown), $\beta = 1.695$ (yellow brown), $\gamma = 1.707$ (dark yellow brown); $r > v$, strong. Crystals short prismatic. Analysis led to the formula $Mn_3Fe_3(PO_4)_4(OH)_3 \cdot 7H_2O$. This mineral resembles type xanthoxenite more closely than does the previously described xanthoxenite from Palermo.

Physical properties and occurrence of a reddish-brown mineral from Greenbelt, Maryland, resemble those reported for azovskite. Crystals line shrinkage cavities in concretionary nodules consisting primarily of quartz grains, limonite, and phosphate minerals. Monoclinic with $a_0 = 7.76$ Å, $b_0 = 12.25$, $c_0 = 6.11$, $\beta = 90°59'$; space group $P2_1/n$. Biaxial positive; $\alpha = 1.740$ (pale reddish brown), $\beta = 1.752$ (reddish brown); 2V moderate; $r < v$, strong, The analysis led to two possible formulas, $Fe_3(PO_4)_2(OH)_3 \cdot 6H_2O$ and $Fe_3(PO_4)_2(OH)_3 \cdot 2.5H_2O$ (excluding H_2O-), neither of which corresponds to that of azovskite. Specific gravity 2.55 (meas.), 2.59 (calc. for $2.5H_2O$). Naming of mineral postponed pending X-ray comparison with azovskite.

RELATIVE AGE OF FOLSOM MAN AND THE CAPULIN MOUNTAIN ERUPTION, COLFAX AND UNION COUNTIES, NEW MEXICO*

William R. Muehlberger
Department of Geology, The University of Texas, Austin, Texas

Two stages of alluviation can be recognized at the type Folsom Man locality, eastern Colfax County, New Mexico. The older, yellowish, caliche-bearing alluvium is similar to other Folsom-bearing deposits of the southern High Plains which have radiocarbon ages near 8000 B.C. Erosion of the older alluvium occurred before deposition of the dark, humus-rich, younger alluvium. Charcoal found in a fire pit near the base of the younger alluvium near the Folsom Man locality has a radiocarbon age of 2350 ± 250 B.C.

Four volcanoes of the most recent eruptive cycle, the Capulin age of Collins, sent flows into the Dry Cimarron River near Folsom, 9 miles downstream from the Folsom Man locality. From oldest to youngest these were Capulin Mountain, Baby Capulin Mountain, Twin Mountain, and Purvine Hills. A single minor flow from Capulin Mountain reached the Dry Cimarron River where it overlies the older alluvium and is buried in the younger alluvium. Thus Capulin Mountain erupted between 8000 B.C. and 2400 B.C. Flows from both Baby Capulin Mountain and Purvine Hills thoroughly

* Presented by permission of the Director, New Mexico Bureau of Mines and Mineral Resources.

obstructed the river and should have caused alluviation prior to new channels being cut through the lava dam. Twin Mountain was principally a cinder eruption contemporaneous with the flows from Purvine Hills. The absence of unconformities in the younger soil which would reflect these breaks in the alluvial history suggests that all these eruptions occurred prior to the deposition of the younger soil or earlier than 2400 B.C.

MINERAL COMPOSITION ON AND ADJACENT TO A SEAMOUNT IN SIGSBEE DEEP

Haydn H. Murray and Jack L. Harrison
Dept. of Geology, Indiana University, Bloomington, Ind.

Six cores from the Sigsbee deep in the western Gulf of Mexico were obtained from the Lamont Geological Observatory for mineralogical studies. Two cores came from a low seamount that rises approximately 200 fathoms above the bottom of the deep. Two other cores are from the edge of the seamount, and the remaining two cores are from the abyssal plain surrounding the seamount. The cores from the abyssal plain are characterized by a series of graded layers of silt and clay, whereas those on the seamount do not show grading.

Mineralogically these cores contain variable proportions of quartz, calcite, montmorillonite, illite, chlorite, and a minor amount of kaolinite. Montmorillonite is the most abundant clay mineral present, which was unexpected because previous knowledge of the clay minerals in marine sediments indicated that illite and chlorite are the dominant clay minerals in this environment. The presence of large quantities of montmorillonite in the abyssal sediments may indicate that much of the montmorillonite carried into the Gulf of Mexico by rivers is not deposited on the continental shelf but is held in suspension and deposited in deep and quiet water far from shore. Previous reports indicate that the shallow shelf areas are characterized by the presence of illite and chlorite. In general the illite and chlorite in the cores are better developed in sediments that lie below the present surface, even at a depth of a few centimeters, indicating some crystal structure reorganization during diagenesis.

MINERALOGY OF THE BEDFORD FORMATION AND RELATED ROCKS IN NORTHERN OHIO

Bruce W. Nelson
Department of Geology, University of Illinois, Urbana, Ill.

The mineralogy of the lower Mississippian Berea, Bedford, and Cussewago and upper Devonian Cleveland, Chagrin, and Huron formations of northern Ohio is described. The rocks vary from quartz-illite-chlorite-kaolinite rocks containing abundant kaolinite to quartz-illite-chlorite rocks containing no kaolinite. The Berea and Bedford sandstones and siltstones are quartz-illite-chlorite-kaolinite rocks. The Bedford gray and reddish shales are highly kaolinitic quartz-illite-chlorite-kaolinite rocks. East of Cleveland, Ohio, the Chagrin gray siltstones and shales are moderately kaolinitic quartz-illite-chlorite-kaolinite rocks. At Cleveland the Chagrin formation passes westward into dark-gray and black shales containing little kaolinite. The Cleveland black, carbonaceous shale is a quartz-illite-chlorite rock containing no kaolinite. The Huron formation of north-central Ohio is composed of black, carbonaceous shales and gray shales which contain no kaolinite. This formation consists of quartz-illite-chlorite rocks exclusively. Quartz of less than 1 micron particle size occurs in the Cleveland and Huron shales. The reddish Bedford shales contain hematite.

Field relations suggest that these rocks were derived from the east. Regional and stratigraphic clay-mineral variations (above) appear to have been controlled by differential clay-mineral flocculation during sedimentation. The black, carbonaceous shales seem to have had a deep-water origin, where land-derived organic matter and inorganic detritus accumulated under quiet but not necessarily euxenic conditions.

UPPER CROIXAN STRATIGRAPHY OF THE UPPER MISSISSIPPI VALLEY

C. A. Nelson
University of California, Los Angeles, Calif.

The type Upper Croixan strata of the Upper Mississippi Valley consist of dolomite and dolomitic siltstone and sandstone and overlying massive nondolomitic sandstone lying above the glauconitic sandstone of the Franconia formation and below lower Ordovician dolomite. Previous subdivisions have employed both faunal and lithic criteria for discrimination of formations and members.

The strata can readily be divided on lithic characters alone, and such formation and member divisions are markedly time transgressive. This transgressive character is best shown by the biostratigraphic climb of the upper sandstone unit from shoreward to basinward facies. The terminology adopted represents a return to early lithic classifications in which the St. Lawrence and Jordan formations are recognized as comprising the dolomitic strata and the massive sandstones, respectively. The St. Lawrence is further divided into the Black Earth member (basal sandy and silty dolomite, essentially a basinward facies which thins to disappearance shoreward) and the Lodi member (dolomitic siltstone and fine-grained silty and dolomitic sandstone of the shoreward facies).

It is urged that Trempealeau, presently employed and generally accepted as a formation including all the above strata, and as a stage, be restricted in usage to Trempealeauan Stage.

EARTHQUAKE FOCAL DEPTHS IN THE PUGET SOUND AREA, WASHINGTON

Frank Neumann
Geology Department, University of Washington, Seattle, Wash.

Epicenters and focal depths of nine earthquakes in the Puget Sound area (November 1953 through March 1955) were determined from regional seismographic data. In the immediate Sound area, 60-70-km depths were found for four shocks; this group is roughly aligned with the lower portion Georgia Strait, B.C. Shocks of 30-km depth were found in the northern suburb of Seattle and just east of Everett; three of 15-km depth were distributed over the northern portion of the Olympic Peninsula. The depths were obtained by using a compressional wave speed of 6.80 km/sec obtained from other regional shocks in which the depth had but little effect on the observed speed between stations that were in radial alignment with the epicenters.

Consistent results were obtained only by assuming that, above these foci, there was no rock in which the velocity was greater than 6.8 km/sec. This would place the Mohorovičić discontinuity at least as low as the deepest foci found—namely, 60 to 70 km. Efforts to obtain consistent results with a shallower discontinuity, using a speed of 8.1 km/sec in the lower layer, failed. Normally the Mohorovičić discontinuity is found at depths of about 30 km in continental areas, increasing to depths of 60 and 70 km beneath mountain ranges. The destructive shock of April 13, 1949, between Olympia and Tacoma, also had a depth of about 70 km, agreeing well with the depths of the lighter shocks currently being registered.

BIOGEOLOGICAL RECONNAISSANCE OF THE NORTHWESTERN PART OF THE GREAT BAHAMA BANK

Norman D. Newell and John Imbrie
American Museum of Natural History, New York, N. Y.

The regional ecology and geology of the northwestern part of the Great Bahama Bank form the subject of a series of studies based at the Lerner Marine Laboratory, Bimini. The object of these studies is to obtain knowledge of marine processes in a warm, clear, shelf sea.

The profile of the Bank edge, as determined by echo soundings, consists of a terraced outer plat-

form marked by submerged shore lines, a barrier rim of oölite cays and oölitic sand, and a shallow shelf lagoon. Sediments outside the barrier rim are mainly shell detritus; inside the rim they are oölitic. Coral reefs are absent in the region. Effects of salinity and currents on sedimentation and ecology were studied. A photogrammetric geologic-ecologic map was made of Bimini and vicinity. The erosional shore profile shows interesting analogy to Pacific coral reefs perhaps shedding further light on the significance of some reef profiles.

ENGINEERING GEOLOGY OF THE THARTAR PROJECT, IRAQ

John O. Nigra
U. S. Educational Foundation, Baghdad, Iraq, and Department of Geology, Tulane University, New Orleans, La.

Limiting the flood discharge of the Tigris and diverting excess water along a terraced-earth channelway into the Thartar depression are objectives of a significant Iraqui project. The depression represents the widening of Wadi Thartar at Lat. 34° N. into a large, ephemerally dry salt lake of about 40,000 acres, with an elevation 10 feet below sea level at its center. The origin of this feature, much disputed, is believed chiefly attributable to solution subsidence in flat, underlying carbonate and evaporite beds rather than to downfaulting or wind erosion.

Difference of opinion also exists as to whether this natural reservoir between two extensive river valleys is water tight. Although the base levels of the Euphrates and Tigris are above the bottom of the sink, which is separated from the twin rivers by the high ground of the Jezirah desert, seepage appears to be precluded by a hydraulic gradient sloping less than the shallow regional east dips of the subjacent Euphrates (lower Miocene) reef limestone and Lower Fars (upper Miocene) marine limestone, anhydrite, and gypsum with alternating impervious beds of shale.

The Thartar basin is expected to hold 68 billion cubic meters of water within 870 square miles when filled to the plus 200-foot contour. This is the critical level above which seepage can easily occur into aquiferous Bakhtiari (Pliocene) conglomerate above Upper Fars nonmarine soft clays and marls. The impounded water may become somewhat saline but will be useful for irrigation.

GEOPHYSICAL INVESTIGATIONS IN THE EASTERN CARIBBEAN, VENEZUELAN BASIN, AVES SWELL, GRENADA TROUGH, LESSER ANTILLES, PUERTO RICO, AND PUERTO RICO TROUGH

C. B. Officer, J. Ewing, R. S. Edwards, and H. R. Johnson
Rice Institute and Woods Hole Oceanographic Institution; Lamont Geological Observatory; Woods Hole Oceanographic Institution; Woods Hole Oceanographic Institution

During the spring of 1955, 47 seismic-refraction profiles were made over the Eastern Caribbean and adjacent areas from the research vessels ATLANTIS and CARYN. This paper discusses the geophysical results and the interpretation of these geophysical results in relation to geologic structure for the profiles that were made over the Venezuelan Basin, Aves Swell, Grenada Trough, Lesser Antilles, Puerto Rico, and Puerto Rico Trough. There is considerable variation in the structure from one area to the next and within a given area. The material below the discontinuity is not uniform and shows measurable differences in seismic velocity from one profile to the next. There is some thickening of the crust beneath the Puerto Rico Trough but not of the dimensions originally considered for a downbuckle. All these profiles indicate that the Eastern Caribbean has been built up from an oceanic crust rather than that it is a reworked continental mass. It is believed that it is necessary to look for subcrustal forces rather than strictly crustal forces for the tectonic origin of the island-arc features of the Caribbean.

SUBSIDENCE TROUGHS IN THE CASTILE ANHYDRITE OF THE GYPSUM PLAIN, NEW MEXICO AND TEXAS

Wilds W. Olive
Gulf Oil Corporation, Gulf Building, Pittsburgh, Pa.

Subsidence troughs are straight, narrow depressions ranging in width from a few hundred feet to 1 mile, and in length from about half a mile to 10 miles. The troughs are formed by subsidence of near-surface earth blocks to fill voids dissolved by underground waters moving along subjacent drainage channels which flow parallel to the troughs. Numerous subsidence troughs are developed in the Castile anhydrite (upper Permian) of the Gypsum Plain in West Texas and southeastern New Mexico where they characteristically have broad, relatively flat bottoms bounded by gentle slopes rising 15 to 20 feet to narrow, straight divides which stand 2–3 feet above the general level of the Gypsum Plain. The troughs trend roughly parallel to the direction of the regional dip, about 3° E. Sink holes, as deep as 30 feet, commonly occur in and near the troughs. Many deep subsidence cracks enlarged by solution cut across the troughs at different angles. Several caves up to 6 feet in diameter parallel the troughs. Displacement and local folding in strata of the Castile anhydrite in and near the troughs are not reflected in the Lamar limestone member of the Bell Canyon formation (lower Permian) which conformably underlies the Castile. The trends and spacing of the underground channels are probably related to an easterly trending joint set and/or linear, easterly trending zones of intense jointing.

COMPUTATION OF CHEMICAL ANALYSES OF COAL SPEEDED BY USE OF IBM PUNCHED CARDS*

Margaret A. Parker
Illinois State Geological Survey, Urbana, Ill.

The recording of chemical analyses in punched cards facilitates the integration of chemical data with geological data for mines and drill holes. The punched cards may be used to prepare copy for offset printing and reduce costs of publishing the analyses.

The results of the chemical analysis of coal are punched into cards for computation by electronic machine to obtain proximate and ultimate analyses of coal air dried, as received, moisture free, moisture and ash free, dry unit coal, and moist unit coal. Calorific value and B.t.u. can also be obtained. Because of the speed of the electronic calculating machines, about 100 analyses are normally the minimum that should be calculated at one time.

Where the volume of analyses is not sufficient to warrant the use of electronic calculating machines, the analyses can be punched directly into cards, crossfiled, and used for publication.

The proposed method for handling chemical analyses is the result of work at the Illinois State Geological Survey, the University of Sydney, and the Joint Coal Board, Sydney, Australia. The work at the Australian institutions was done under a Fulbright research grant.

MACROFAUNA AND BATHYMETRY OF CALCAREOUS BANKS ON THE CONTINENTAL SHELF OF THE NORTHERN GULF OF MEXICO†

Robert H. Parker and Joseph R. Curray
Scripps Institution of Oceanography, La Jolla, Calif.

Samples were taken from the top, sides, and vicinity of calcareous banks on the outer continental shelf of the northern Gulf of Mexico, supplemented by core material from Lamont Geological Observa-

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* Presented with permission of the Chief, Illinois State Geological Survey

† This investigation was supported by a grant from the American Petroleum Institute, Project 51.

tory. Contours and profiles are based on Scripps fathometer surveys and unpublished hydrographic sheets of the Coast and Geodetic Survey. These show that the topography of the banks is extremely uneven, but in many places surrounded by ring depressions.

The macro-organisms from these banks are different from those in the surrounding shelf sediments. Most of the bank faunas have been reported only from southern Florida, the West Indies, and the Caribbean, thus representing subtropical conditions rather than the cooler temperate waters inshore. The mollusks are those usually associated with a coral or rock bottom; they are either permanently attached or dependent upon the organisms making up these reefs. Although some living corals were taken on these banks, they are uncommon, and most of them are solitary species rather than reef-forming or colonial forms. The tops of the banks appear to be covered primarily by various species of living lithothamniods and Bryozoa. The finding of gypsum and rock fragments in a core from the vicinity of one bank may bear on its origin.

IMPLICATIONS OF GENERAL EDUCATION FOR THE TESTING PROGRAM IN GEOLOGY

William H. Parsons
Department of Geology, Allegheny College, Meadville, Pa.

Geology teachers in a dozen eastern and central colleges who have responsibility for creating and teaching specially designed courses in science in general education have modified their approach to geology courses as follows: (1) reduced stress of factual knowledge with increased emphasis on understanding, organization, synthesis; (2) departed from nicely contrived lectures to discussion of problems of application of concepts the student can learn from his own reading; (3) considered the student as a participant, not merely as a neutral observer; (4) redefined the objectives of the basic geology courses in the direction of a balance between being shown the tools and of knowing how and when to use them; (5) provided for testing not only facts but skills, understandings, judgments, appreciations.

Least progress has been made in evaluation (5). The average teacher still asks almost entirely for factual data, and the average undergraduate, no matter how fine the classes, will gauge his efforts toward ends stressed in the examinations. We must make concerted efforts to measure ability to select and organize data, quantify, judge relevance, recommend procedures, and relate geology to other phases of learning.

Samples of such test items are offered, along with a form for plotting items against course objectives. Written tests may fail to measure certain abilities revealed by more subjective judgments (*e.g.*, senior projects, choice of reading material).

AGE AND CORRELATION OF THE LOWER CRETACEOUS AURORA LIMESTONE, SIERRA DE TLAHUALILO, COAHUILA, MEXICO

Bob F. Perkins
Department of Geology, Southern Methodist University, Dallas, Texas

This paper contributes to the stratigraphic and structural studies of the Cretaceous of northern Mexico being conducted by the University of Michigan Museum of Paleontology under Professor Lewis B. Kellum. In the type area (Cuchillo Parado, Chihuahua) the Aurora limestone is a thickly bedded, massive, rudistid-bearing formation of middle and late Albian age and is correlated with the Fredericksburg and Georgetown limestone of Texas. Elsewhere in northern Mexico it is reported to be of early and middle Albian age.

In the Sierra de Tlahualilo the Aurora consists of more than 900 feet of marly, nodular, and massive limestones, dolomite, and gypsum. It is divided into three members of which only the upper, a 365-foot alternating massive nodular limestone member, is fossiliferous. The fossils occur in two zones. One, in the upper 125 feet, is characterized by a new species of *Homomya*, and the other, about 50 feet

above the base of the member, is dominated by *Gryphaea mucronata*. Of the 46 species in the fauna 26 were identified with species from the Texas Comanchean. The ranges of these 26 species in Texas are: 15 Washita, 5 Fredericksburg, 3 Washita-Fredericksburg, 1 Trinity, and 2 Trinity-Washita.

Because of the Washitan aspect of the fauna and especially because of the presence of such characteristic middle and upper Washita species as *Cymatoceras hilli*, *Turrilites brazoensis*, *Pholadomya shattucki*, *Pleurotomaria austinensis*, and *Pseudananchys completa*, the upper member of the Aurora is correlated with the middle and upper Washita (upper Albian) of Texas.

PALEOCURRENTS OF LAKE SUPERIOR PRECAMBRIAN QUARTZITES

F. J. Pettijohn
The Johns Hopkins University, Baltimore, Md.

More than 150 measurements of cross-bedding of Lorrain quartzite (Cobalt series), between Lake Superior and Georgian Bay of Lake Huron, show the mean downdip direction to be S. 17° E. Both published and unpublished measurements of cross-bedding of the Sioux, Baraboo, and Sturgeon quartzites are in essential agreement with those of the Lorrain. The uniformity of dip direction of the cross-bedding strongly supports the conclusion that these formations were deposited by currents flowing southeasterly from the older rocks of the Temiskaming province. The rocks of the Grenville province, therefore, could be (but need not necessarily be) the "offshore" equivalent of the Lorrain; they could *not* be the source of the Lorrain.

The inclination of the cross-bedding of the Lorrain (after correction for tectonic tilt) averages 21.4° but commonly exceeds the presumed angle of repose of sand. The abnormally high readings (up to 59°) are ascribed to internal rotation of the cross-bedding laminations during folding. This conclusion is supported by the positive correlation of angle of inclination of cross-beds and angle of dip of the beds proper.

COMPARISON OF THE HARANG AND HACKBERRY FACIES IN SOUTH LOUISIANA

David E. Pope
428 Lynnette Drive, Metairie, La.

The Harang and Hackberry are seaward-thickening argillaceous facies in the younger Tertiary of South Louisiana and adjacent areas. The Harang facies is identified by the Harang foraminiferal fauna and is found near the middle of the South Louisiana Miocene of the eastern coastal parishes. The older Hackberry facies contains the Hackberry foraminiferal assemblage and is found in the Frio formation, which extends across coastal Louisiana and Texas. The Hackberry is best developed, in Louisiana, in the southwestern part of the State.

Study of the Harang facies indicates: (1) the lower limit of the facies in fringe areas is the approximate top of the *Amphistegina* zone rather than the *Discorbis* zone; (2) the approximate updip limit of the facies trends southeast from New Orleans, generally excluding areas east of the Mississippi River; (3) an area of typical development exists in central Lafourche Parish; and (4) *Planulina harangensis* Cushman and Ellisor is not necessarily the best marker for this facies.

Good possibilities for production of hydrocarbons exist both above and below these facies, although production from within the Harang and the Hackberry in their areas of typical development is negligible.

STRATIGRAPHIC RELATIONSHIPS OF THE FORDHAM GNEISS IN SOUTHEASTERN NEW YORK*

John James Prucha
New York Geological Survey, State Educational Bldg., Albany, N. Y.

Geologic mapping in the Croton Falls and Peach Lake quadrangles south of the Hudson Highlands in southeastern New York has shown that the Fordham gneiss is a wholly conformable and integral

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part of the metasedimentary Manhattan group. The Manhattan group is younger than the Precambrian gneisses of the Hudson Highlands and possibly is Ordovician.

The Fordham gneiss is the basal formation of the Manhattan group and is overlain successively by the Inwood limestone and the Manhattan schist. Although the three units are valid formations in a general way, the three lithologic types commonly are interlayered in a manner which precludes the possibility of repetition by folding or faulting. Both Inwood-type and Manhattan-type lithologies occur as distinct zones within the Fordham gneiss, and the Inwood-type lithology is abundantly interlayered with the Manhattan schist. The Lowerre quartzite, which has been reported to underlie the Inwood limestone, is absent, and its validity as a formation is doubted.

It is concluded that the Fordham gneiss is not correlative with the Precambrian gneisses of the Hudson Highlands and could not have been emplaced into the Manhattan group by faulting. The interlayering of the different lithologies reflects original alternation in types of sediments.

Recognition of the Fordham gneiss as an integral part of the Manhattan group, and the absence of the Lowerre quartzite invalidate earlier correlations of the Manhattan group with the Cambro-Ordovician Hudson River group (Poughquag quartzite—Wappinger limestone—Hudson River pelites) based upon presumed similarities in stratigraphic sequence.

PLEISTOCENE OVERFLOW CHANNELS AT LITTLE LAKE, CALIFORNIA

William C. Putnam
Department of Geology, University of California, Los Angeles, Calif.

Little Lake, a small water body immediately east of the southern Sierra Nevada, occupies a former channel excavated by the overflow waters of Owens Lake during the Pleistocene. Little Lake is one of the more significant links in the chain of spillways connecting Owens, Searles, Panamint, and Death valleys.

Several periods of overflow can be recognized (there appear to have been four), and these can be related to three major episodes of volcanism represented by intercanyon basalt flows erupted at various times during the Pleistocene.

Although a local chronology has been established, correlation has not yet been attempted with the glacial stages in the near-by Sierra Nevada, but this may soon prove possible for at least the events of the latter part of the Epoch.

VALIDITY OF THE SO-CALLED OHIO RIVER FORMATION OF SOUTHERN INDIANA

Louis L. Ray
U. S. Geological Survey, Washington, D. C.

In Harrison, Washington, Clark, and Floyd counties of southern Indiana, deposits of loose to poorly consolidated white, brown to red, cross-bedded sand with some clay, quartz pebbles, and a basal conglomerate occur as erosional remnants on residual uplands and summits which have been correlated with the Lexington Plain. Many diverse interpretations have been made regarding the genesis of these deposits, named the Ohio River formation by G. H. Ashley in 1903. Their suggested age has ranged from Cretaceous (?) to Pliocene.

Recent studies show that the lithology and stratigraphic position of the Ohio River formation in Indiana are the same as those of the Tip Top sand deposits, only a few miles away and across the Ohio Valley in Kentucky. In both areas the deposits are isolated remnants of sandstone of Chester age, resting unconformably on older limestones of the Meramec group.

It has been suggested previously that the name Tip Top sand be abandoned. It is suggested here that the name Ohio River formation likewise be abandoned, since the deposits are correlative with the lowest sandstone of the Chester group in this area and are part of the normal stratigraphic sequence. The possibility of this correlation was suggested as early as 1908 by R. W. Ellis. A regional extension

of the large unconformity previously recognized in Kentucky at the base of the lowest sandstone of Chester age, is indicated.

STRATIGRAPHY AND PALEOECOLOGY OF THE LOWER DEVONIAN HELDERBERGIAN SERIES OF NEW YORK

Lawrence V. Rickard
Warnerville, N. Y.

Westward from the Helderbergs of eastern New York, the Coeymans limestone thickens to nearly 100 feet at Cherry Valley. This greatly thickened Coeymans then splits into three parts—the lower and middle portions grade laterally into the Olney, Elmwood, Clark Reservation, and Jamesville members of the type Manlius limestone; the upper portion continues westward to Chittenango Falls. Thus nearly all the Manlius in central New York is a facies of the Coeymans of eastern New York and consequently should be included in the Lower Devonian. The Manlius of eastern New York is entirely pre-Olney. It thins westwardly, is absent west of Jamesville, and is seemingly replaced by the underlying thickening Rondout dolomite. The Kalkberg limestone also thickens westwardly and extends to Oriskany Falls, apparently replacing the New Scotland shaly limestone of eastern New York. The New Scotland and Becraft limestones are unknown west of Sharon Springs.

Each of the above formations was deposited in a particular environment. Five phases can be distinguished, each marked by distinctive lithologies and faunas. They represent biotopes interpreted as "lagoonal", "biostromal", epineritic, and infraneritic (shallow and deep). These phases (or formations) become younger as they are traced westward into central New York; the more landward "lagoonal" and "biostromal" phases replace the epi- and infraneritic phases along a given horizon. This interpretation may also be applied to the Keyser limestone and overlying units of central Pennsylvania and Maryland. The Silurian-Devonian boundary appears to be stratigraphically lower than it currently is placed.

FIELDS OF STABILITY OF JADEITE, KYANITE, AND PYROPE*

Eugene C. Robertson, Francis Birch, and Gordon J. F. MacDonald
Dunbar Laboratory, Harvard University, Cambridge, Mass.

The fields of stability of several minerals of the eclogite association have been investigated at pressures between 10,000 and 30,000 bars, and temperatures between 600° and 1300°C. The pressure apparatus is an enlarged version of Bridgman's double system, with a conical inner chamber supported externally by heavy rings. The pressure medium is nitrogen. Temperatures are produced by an internal wire-wound furnace in which are heated small gold or platinum capsules containing the charges.

Most of the results apply to the reaction, 2 jadeite = albite + nepheline, for which the equilibrium line is given by the equation, $P = 500 + 19.3\ T$, where P is pressure in bars and T the centigrade temperature; the experimental points lie in the interval between 600°C, 12,200 bars and 1200°C, 22,700 bars. Jadeite crystallizes on the high-pressure side of this line, either from glass of jadeite composition or from an albite-nepheline mixture; below 800°C, water was added to accelerate the reaction. The identification is based on the known jadeite x-ray pattern given by a North American Phillips high-angle diffractometer and on the indices of refraction. The position of the jadeite melting curve has also been roughly fixed.

Additional results include a tentative boundary between the kyanite and sillimanite fields, and several points in the pyrope field.

* Work supported in part by the Office of Naval Research.

GEOLOGICAL SIGNIFICANCE OF RADON IN STREAM AND WELL WATERS

Allen S. Rogers
U. S. Geological Survey, Salt Lake City, Utah

The distribution of radon in mountain streams near Salt Lake City, Utah, was used to locate points where relatively large amounts of radon-bearing ground water enter the stream, although other evidence of spring activity may be lacking. These points of influent ground water are marked by abrupt anomalous increases in the radon content of the stream waters (as much as two orders of magnitude within a linear distance of 50 feet).

The abnormal concentration of radon is rapidly dissipated to the atmosphere; the rate is an exponential function of various slopes with respect to distance of stream flow.

Major increments of addition of ground water to stream flow can be estimated on the basis of radon concentrations in stream and related spring waters. The radon content of the stream waters can generally be related to specific stratigraphic horizons in different drainage areas.

Contours of radon concentrations in waters from 130 wells show well-defined, linear highs over two known faults in unconsolidated valley fill. Several additional parallel highs suggest a series of en echelon faults not otherwise evident. An observed regional variation in the general radon background is attributed to a corresponding variation in the sediments. In the area of high background the sediments are derived from adjacent highlands of schist and gneiss; in the low background region a conglomerate is the source.

In all waters studied radon is unsupported by radium in solution.

PALEOPEDOLOGIC STUDY AT THE LINDENMEIER SITE, COLORADO*

B. N. Rolfe
U. S. Geological Survey, Federal Center, Denver, Colo.

A soil profile at the Lindenmeier Site, Colorado, was selected for paleopedologic study because of previous geologic investigations at this location. The purpose was to develop criteria for recognition of paleosol environments.

Examination of the profile morphology indicated the possible existence of two to four pedogenic entities in the 12-foot section overlying the Folsom culture layer. Laboratory analyses consisted of particle-size distribution, pH, and calcium-carbonate content of the bulk samples followed by x-ray diffraction and ethylene glycol adsorption studies of the clay fraction.

The profile was developed in an alluvial flat, a topographically azonal pedologic position. Conclusions from morphological observations are therefore suspect. Study emphasis was placed on the mineralogy of the clay fraction because bulk-sample analyses revealed no interpretive differences. The source of the nongravel material in the profile is apparently Brule, a geologic formation whose clay fraction is dominantly montmorillonite. Montmorillonite weathers to a hydrous mica or kaolin; the amount of change is a function of time and intensity.

Clay studies confirmed the presence of four soil zones. A comparison of present findings with those of Bryan and Ray follows:

Zone	Diagnostic Minerals	Inferred Climate	Bryan and Ray
Wind-blown surface	Montmorillonite	Semiarid	Semiarid
Intermediate soil	Hydrous mica—montmorillonite	Subhumid	"Similar to surface"
2-foot soil	Montmorillonite	Arid	"Similar to surface"
Culture layer	Montmorillonite—hydrous mica	Subhumid	Subhumid?
Reworked Brule	Hydrous mica	Humid	Humid

* Approved for publication by the Director, U. S. Geological Survey

STABILITY OF MINERALS IN THE SYSTEM ZnO—SiO_2—H_2O

D. M. Roy and F. A. Mumpton
Dept. of Geophysics and Geochemistry, College of Mineral Industries, The Pennsylvania State University, University Park, Pa.

Phase-equilibrium relations in the system ZnO—SiO_2—H_2O have been studied in the temperature range 130°–800°C, H_2O pressures of 500 to 20,000 psi. Stability regions were found for willemite, hemimorphite, sauconite, $Zn(OH)_2$, and ZnO(zincite). The reaction, hemimorphite $\rightleftharpoons$ willemite + H_2O takes place at about 240°C at 15,000 psi, and as expected the equilibrium temperature does not change more than 10°C from this value for pressure changes down to 7,500 psi or up to 30,000 psi. This sets an upper temperature limit for hemimorphite deposits of about 250°C. Although the same temperature constitutes the lower stability limit for willemite in the presence of water, the rehydration is extremely difficult and may not have taken place under certain natural conditions. A montmorillonid phase representing a pure zinc-silica sauconite (analogous to stevensite) was prepared (often alone) from mixtures of varying composition near the $3ZnO:4SiO_2$ ratio. Its temperature-stability limit at 20,000 psi is about 210°C, again showing but little variation with pressure down to 10,000 psi. Various polymorphic forms of $Zn(OH)_2$ are encountered, and at least one of them has not been fully described elsewhere. Complex metastability relationships among these and the difficulty in hydrating zincite even at 20,000 psi for 2 weeks make interpretation of these latter data difficult.

TECTONIC HISTORY OF PART OF THE DOS CABEZAS AND CHIRICAHUA MOUNTAINS, ARIZONA

Floyd F. Sabins
California Research Corporation, La Habra, Calif.

The Dos Cabezas and the Chiricahua mountains, which together constitute a Basin Range in Cochise County, show evidence for at least four periods of tectonic activity. A Precambrian orogeny folded and metamorphosed a clastic sequence of unknown thickness to form the Pinal schist. A minor synkinematic granitic body was emplaced during the orogeny, and a major post-kinematic Precambrian granitic body was emplaced after the orogeny.

The 7600 feet of Paleozoic strata overlying the Precambrian basement complex ranges from Cambrian through Permian. The widespread disconformity between the Lower Ordovician and Upper Devonian strata records a major epeirogenic uplift.

The pronounced angular discordance between the Paleozoic strata and the overlying Lower Cretaceous strata was caused by a Mesozoic orogeny that also supplied the great volume of coarse clastic sediments forming the basal conglomerate of the Lower Cretaceous.

All the pre-Cenozoic rocks were involved in the Laramide orogeny which resulted in three major overlapping thrust plates that probably moved from southwest to northeast. One plate is folded into a major northwest-trending syncline, and all the plates are cut by numerous tear faults. Many diorite and quartz monzonite intrusives cut the Laramide structures.

Cenozoic volcanic rocks apparently post-date the Laramide orogeny but were affected by the Basin Range faulting that tilted the range steeply to the southwest and elevated it relative to the adjacent structural valleys. Erosion has obscured the northwest-trending border faults, but subsurface data show that a zone of great vertical displacement borders the northeast range front.

MONTMORILLONITES STABLE AT HIGH TEMPERATURE

L. B. Sand
Department of Mineralogy, University of Utah, Salt Lake City, Utah

Recent hydrothermal investigations have reported the maximum thermal stability of synthetic montmorillonites to be about 480°C at 15,000 psi.

The addition of a few per cent of soda and lithia to a montmorillonite composition near that of saponite produces a phase stable to high temperature. Of the compositions studied, the composition $Na_{.33}Li_{.17}Mg_{2.67}Al_{.67}Si_{3.33}$ formed a montmorillonite stable to the highest temperature (800°C) at 15,000 psi H_2O pressures. This composition, with the exception of fluorine content, is similar to that of hectorite. The maximum thermal stability of a hectorite sample, under the same hydrothermal conditions, was found to be 850°C. Since the montmorillonite composition which apparently gives the highest thermal stability is that of hectorite, the question arises whether hectorite, being an optimum composition, was formed at high temperature, or whether the relation is fortuitous.

X-ray-diffraction, differential-thermal-analysis, and base-exchange-capacity data and electron micrographs show the close similarity between hectorite and the synthetic montmorillonite of analogous composition.

PETROGRAPHY AND REGIONAL CHARACTERISTICS OF THE LOWER KITTANNING COAL

Norman Schapiro and Aureal T. Cross
West Virginia University and West Virginia Geological Survey, Morgantown, W. Va.

Polished-surface preparations of complete channels of 21 samples of Lower Kittanning coal from West Virginia, Ohio, and Pennsylvania have been examined under low magnification and the results compared with studies of 5 of these coals examined under high magnification by both transmitted and reflected light.

A detailed comparison was made between results of continuous-transect and point-count methods of recording total constituent particles. A study to determine the reliability, quality of representation, and utility of analyses of selected slides or units as compared with complete columns showed comparable representation. The results demonstrate the point-count method to be reliable, faster, and to have greater accuracy and utility in tabulating finer-size constituents.

A simplified composite classification of coal components and constituents was devised in which several size units are recognized for some constituents. This allows the uniform recording of petrographic units by either reflected- or transmitted-light techniques and the regrouping of these data for comparison with those from studies using different classifications or methods. This also makes it possible to tabulate the amounts of various size fractions of ingredients in various ways for utilization in coal beneficiation. There is considerable latitude in the components themselves, and legislated definitions of these are not acceptable.

No evident relationship of bright to dull or cannel coal to regional position is evident based on petrographic evaluation. There is an expectable change in quality of anthraxylon and translucent attritus to the east associated with increase in rank. Local influences on petrographic composition are more important.

CONCEPT, TECHNIQUE, AND LANGUAGE IN COAL PETROLOGY

J. M. Schopf and R. J. Gray
U. S. Geological Survey, Columbus, Ohio

Ideas, methods, and expression are closely interrelated in any field of science during its period of rapid growth. In development of coal geology all phases are evolving together, and the stability of basic concept that characterizes long-established disciplines is not conspicuous in this field. For example, the parameters of *type*, *rank*, and *grade* variation in coal, concepts fundamental to organization of modern information about this singular class of rocks, are still not precisely defined. The technical meaning now attached to these terms has evolved almost entirely within our own lifetimes.

The *techniques of differentiation* seem as essential as *ideas about differentiation* for determination of

types of coal. From about 1920 to 1930 ideas apparently outstripped development of differentiative methods. The original ideas were not sufficiently explicit with regard to method, and this has been a source of confusion and continuing difficulty in expression. Controversy about coal petrologic terms is a symptom of poorly defined methodology, rather than the result of an essential conflict in concept.

Quantitative methods for microdifferentiation of coal were applied by Thiessen in 1931. A practical method, generalized in some particulars, was devised first. Recently we have developed a more explicit method of component analysis. This method provides a means for detailed quantitative integration of the types of coal. It can serve as a common basis for expressing differences between the various systems of routine analytic coal microscopy. It should enable us to evaluate better the variations of petrologic composition and texture that denote differences in type and to relate these variations to rank and grade for purposes of scientific classification.

NEW MID-PLEISTOCENE FOSSIL QUARRY IN SOUTHERN NEBRASKA

C. Bertrand Schultz and Lloyd G. Tanner
Dept. of Geology, Univ. of Nebraska, and Univ. of Nebraska State Museum, Lincoln, Nebr.

A new fossil quarry, containing the remains of both vertebrates and invertebrates, has been discovered in south-central Nebraska (1½ miles south and west of Angus in Nuckolls County). The fossils are preserved in Sappa silts in a lime concentration zone (C horizon) of a Yarmouth paleosol. The calcium carbonate appears to have been responsible for the preservation of fragile invertebrate as well as vertebrate fossils. The mammalian remains range from small rodents to large proboscidians. Fossilized specimens of fish, reptiles, amphibians, and birds also are present in the deposits. The importance of this locality is emphasized because of its nearness to the glacial till border (less than 40 miles), thus enabling a more definite geologic dating of the fossils. A second fossil quarry, with a similar faunal assemblage and also associated with a Yarmouth paleosol, has been located 26 miles north of Lincoln in Saunders County, Nebraska. This locality is within the Kansan till border, thus dating it definitely as post-Kansan. The faunas from both localities compare favorably with the well-known Pleistocene fauna from Hay Springs, Sheridan County, Nebraska. A better understanding of the paleoecology of the medial Pleistocene of the Nebraska region also has been gained by the study of the geology and fossils of these new sites.

GEOLOGICAL PROBLEMS IN THE DESIGN AND CONSTRUCTION OF FLOOD-CONTROL STRUCTURES IN THE MISSISSIPPI ALLUVIAL VALLEY

John R. Schultz
Waterways Experiment Station, Vicksburg, Miss.

Nearly all geological problems connected with design and construction of flood-control structures (levees, earth dams, outlet structures, and drainage channels) in the Mississippi alluvial valley are related to a sand and gravel substratum and a fine-grained top stratum of highly variable thickness. The substratum affords the best foundation for heavy structures but is highly permeable, and careful dewatering is necessary in excavations that penetrate any considerable thickness of the topstratum. Major irregularities in thickness of the topstratum, clay plugs for example, also have considerable influence on localization of seepage under levees and other water barriers. Distribution of discontinuities in the topstratum, orientation of clay-filled swales for example, is, therefore, a major consideration in the location of water barriers as well as the governing factor in the spacing of relief wells or other devices designed to alleviate uplift pressures caused by underseepage.

Clay plugs, or other thick deposits of cohesive materials, are more resistant to erosion by the river than sands and other more or less cohesionless materials and tend greatly to retard bank re-

cession. Thick deposits of cohesive materials may also have an important influence on the future direction of bank migration. Consequently, an analysis of bank stability and probable future trends of bank migration is an important factor in selecting locations for large permanent structures.

PETROLOGY OF UNDERCLAYS

Leonard G. Schultz
U. S. Geological Survey, Beltsville, Md.

Four hundred samples of Pennsylvanian underclays and associated rocks from the Appalachian, Illinois, and Mid-Continent basins were analyzed to determine their regional, stratigraphic, and profile variations in mineralogy. Plastic underclays are mixtures, principally of kaolinite, illite, mixed-layer illite-montmorillonite, quartz, and in some samples a 14A component ranging from vermiculite to chlorite; mineralogically, shales closely parallel near-by underclays, but they commonly contain less kaolinite and mixed-layer material and more crystalline chlorite.

Regionally, underclays are characteristically less kaolinitic in the geosynclinal parts of sedimentary basins than in the shelf areas. Stratigraphically, lower Pennsylvanian underclays are more kaolinitic than those from the upper Pennsylvanian. Using National Research Council correlations and coal terminology of the State of Illinois, the kaolinite-content decrease, which is first noted in the No. 2 coal underclay in the Mid-Continent basin, is not evident until the No. 6 coal underclay in the Appalachian basin where the change is much less marked. The underclays in parts of the column with abundant marine beds tend to contain little kaolinite and abundant mixed-layer clay.

Field observations indicating that underclays were formed before the overlying coals were deposited and lack of profile variations of kaolinite, chlorite, and feldspar show that underclays are not residual. Their mineralogy is thought to be caused by leaching in soils of the source areas during periods of relatively slow erosion; regional and stratigraphic variations of underclays result from different source areas and variations in the type of weathering in the source areas throughout Pennsylvanian time.

INFLUENCE OF CREEP AND RAINWASH ON THE RETREAT OF BADLAND SLOPES

Stanley A. Schumm
U. S. Geological Survey, Technical Coordination Br., Denver Federal Center, Denver, Colo.

In badlands near Wall, South Dakota, creep is suggested as the dominant process modifying slopes developed on the Chadron formation, while rainwash is apparently the major erosional agent on slopes formed on the overlying Brule formation. Creep results from the relatively high permeability of the weathered Chadron clay, while the Brule formation is less permeable causing higher rates of runoff.

The topography developed on each formation is distinctive. Steep, sharp-crested, parallel-retreating slopes with a mean slope angle of 44° are characteristic of the Brule formation. Gentler slopes with broadly convex summits and a mean slope angle of 33° develop on the Chadron formation, where declining slope retreat appears to be important. The topographic differences appear to be similar to those in humid and in arid regions.

Measurement of erosion depth along stake profiles located on small badland residuals reveal that slope retreat is rapid, ranging from 0.4 to 1.0 inch during a 15-month period with 18.7 inches of precipitation. The measured rate of erosion increases with slope angle on the Brule slopes but is at a maximum on the convex divides of the Chadron slopes.

Stake profiles were extended across the pediment surfaces adjacent to the slopes. The pediments were lowered as much as 0.9 inch by rainwash and were extended by the retreat of the badland slopes.

AXIAL-PLANE FOLDING

David M. Scotford
Dept. of Geology, Miami University, Oxford, Ohio

Detailed mapping of the crystalline rock in northeastern Westchester County, New York, has indicated an apparently new structural pattern. This is termed "axial-plane folding" and may be defined as large-scale secondary folding of pre-existing folds in response to movements which varied considerably in direction from those which caused the original folding. Thus the axial planes of the original folds have been folded.

The second episode of folding has exposed the three principal formations in parallel but highly circuitous belts which describe large arcs up to 2 miles in radius.

This structural interpretation is based partially on a stratigraphic revision. The Fordham gneiss-Inwood marble-Manhattan schist sequence is believed to be conformable. The existence of a thrusted unconformity previously placed above the Fordham is seriously doubted. If the conformable nature of the sequence is accepted the mapped pattern allows no other structural interpretation. Drag folds and boudinage structure afford supporting evidence.

The second folding is believed to have occurred when the Highland gneiss block to the northwest was thrust southeastward squeezing the area against a granite mass which acted as a buttress.

STRATIGRAPHIC PATTERN IN PRE-MARMATON DESMOINESIAN CYCLES*

Walter V. Searight
Mo. Geol. Survey & Water Resources, Rolla, Mo.

At least 18 coal-bearing cyclic successions are recognized in strata of pre-Marmaton Desmoinesian age in Missouri, Kansas, and Oklahoma. Each is composed of lithologic units arranged in definite stratigraphic order. Many contain in addition faunal units which likewise follow a stratigraphic pattern within the succession, but individual successions include only part of the characteristic units. The lithologic units differentiated within a cycle from bottom to top include the following: (1) mottled, noncalcareous shale, (2) calcareous shale or dark earthy limestone containing many small productids or Bryozoa, (3) gray shale, (4) calcareous shale or earthy limestone containing mollusks, (5) mudstone or dark shale with siderite concretions, (6) a ledge of massive gray limestone, (7) black fissile shale with phosphatic concretions, (8) fossiliferous limestone with fusulinids, (9) shale with siderite concretions, (10) sandstone, commonly micaceous grading upward into micaceous sandy shale or stigmarian sandstone, (11) hackly, earthy underlimestone, (12) underclay, (13) coal. The stratigraphic order is determined from individual cyclic successions although only a few units are present in each. If a composite cyclic succession be made from all the units recognized, the order from the next lower coal is that given. This "complete" or composite succession has an order or pattern very similar to the megacyclothem of Moore.

GEOMORPHOLOGY OF CIMA DOME, MOJAVE DESERT, CALIFORNIA

Robert P. Sharp
California Institute of Technology, Pasadena, Calif.

Cima Dome is a remarkably smooth symmetrical rock-alluvial dome in the desert of southeastern California. It is a type example of Davis' granitic desert dome, supposedly convex and presumably developed by backwearing on a granitic fault block.

Transit-stadia profiles across Cima Dome reveal concave or essentially straight slopes and show that it is not convex except to slightest degree in the uppermost 25 feet. Complex mechanisms developed to explain the convexity of desert domes do not apply here.

* With permission of the State Geologist of Missouri

Geophysical explorations by resistivity, gravity, and seismic methods on the southeastern flank reveal no boundary fault or any form resembling the convex suballuvial bench deduced by Lawson. Five hundred feet of alluvium and 650 feet of welded rhyolitic tuff(?) overlie the granitic rock floor at its deepest point.

Local geological relations suggest that Cima Dome is an upwarped, stripped, and slightly eroded part of a much more extensive late Pliocene(?) erosion surface, Hewett's Ivanpah Upland, which is buried beneath Pleistocene basaltic volcanics immediately to the west. Support for this interpretation is furnished by a similar but much smaller granitic dome 7 miles southwest where the relations are clearer. The smoothness and symmetry of Cima Dome are due in large part to rapid and uniform weathering by granular disintegration of the coarse quartz monzonite which composes it. Other granitic desert domes have probably evolved by backwearing, but the effects of warping on southern California desert landscapes have been underestimated.

GEOCHEMISTRY OF PELITIC ROCKS

D. M. Shaw
Department of Geology, McMaster University, Hamilton, Ontario, Canada

Compilation of 155 analyses gives the following average composition of all pelitic rocks, from low to high grade (standard deviations in parentheses): SiO_2, 61.54% (4.68%); TiO_2, .82 (.61); Al_2O_3, 16.95 (4.21); Fe_2O_3, 2.56 (1.97); FeO, 3.90 (2.25); MgO, 2.52 (1.91); CaO, 1.76 (2.03); Na_2O, 1.84 (1.18); K_2O, 3.45 (1.32); H_2O, 3.47 (2.25); CO_2, 1.67 (2.37).

After classifying the analyses into two groups (clays, shales, and slates and phyllites, schists, and gneisses) statistical discrimination tests showed no change in composition during regional metamorphism, beyond loss of H_2O and CO_2.

The Littleton formation of New Hampshire is a typical series of pelitic rocks but is not completely representative of the group, since it forms a "sedimentary petrographic province". Thus, the formation is somewhat deficient in CaO, Na_2O, and CO_2, contains more Al_2O_3 and possibly TiO_2, and is in a more reduced state at the low-grade level than the average pelitic rock. It is also more restricted in composition. Moreover, this formation underwent minor metasomatism during metamorphism, resulting in the addition of about ½% of CaO and Na_2O and the loss of H_2O, as well as minor-element changes.

Comparison of pelitic rocks with the average igneous rocks shows that the alkalies and alkaline earths are relatively enriched in shales as follows: Li > K > Na; Sr > Ba > Mg > Ca. These relations cannot be explained solely on the basis of relative ionic potentials.

POST-GLACIAL CONTINENTAL SHELF SEDIMENTATION, NORTHWESTERN GULF OF MEXICO*

Francis P. Shepard and Joseph R. Curray
Scripps Institution of Oceanography, La Jolla, Calif.

A total of 355 cores obtained on Scripps Institution cruises and 15 Lamont Observatory cores plus information from Woods Hole and various petroleum laboratories form a basis for interpreting the post-glacial sedimentation on the shelf west of the Mississippi Delta. A striking feature of the surface-sediment distribution is the marked variation along the outer shelf between dominantly sand areas and dominantly clay areas. Thick sand layers in some of the long cores from the outer shelf have yielded Foraminifera interpreted by Frances Parker as indicating essentially the same environment as do those from the surface layer. This indication that sand is being deposited on the outer shelf is supported by several other cores which are sandy throughout. Sand content may be related to proximity to large rivers.

* This investigation was supported by a grant from the American Petroleum Institute, Project 51

Thicknesses of post-glacial sediments are very uneven. Pleistocene occurs at or near the surface in parts of the Galveston area, whereas some 20-foot cores on the outer shelf do not reach the base of sediments deposited under present-day conditions. However, Phleger showed that one Lamont core at the shelf edge reached shallow-water deposits at about 19 feet. The same special influences appear to have continued to affect areas so that in general samples along the length of a core in one area are more alike than are samples from the same level in cores from contiguous areas.

SUBMARINE CANYONS OF THE FRENCH MEDITERRANEAN

F. P. Shepard and R. L. Fisher
Scripps Institution of Oceanography, La Jolla, Calif.

Along the Mediterranean coast of France and the west coast of Corsica, French surveys have found submarine canyons which extend below the Gibraltar sill depth. The writers accompanied Bourcart and other French geologists in the exploration of selected canyons from these areas and were also taken on field trips along the coasts inside the canyon heads. The writers examined many of the sounding charts and some of the fathograms used as the basis for the intricate pattern of branching canyons shown by Jacques Bourcart. Tentative conclusions follow:

(1) The best-surveyed canyons have river-valley patterns resembling those of Monterey, California.

(2) Submarine canyons of the Gulf of Porto of western Corsica appear to be continuous with the deep gorges cut into the granite on land, and certain canyon heads can be seen through the clear Mediterranean water.

(3) Judging from elevated terraces, the deeply indented coast of western Corsica has had a diastrophic history similar to that of the straight east coast. Probably the larger rivers and greater rainfall of the east coast have caused a straightening of the coast and elimination of submarine canyon heads.

(4) The canyons along the French Riviera, which according to some French dredgings are cut into hard rocks, extend into a few bays where deposition is unimportant.

(5) On the basis of certain piston cores, obtained with our instruments, the canyon axes have more mud filling than American canyons.

GEOLOGY OF THE PEERLESS PEGMATITE, BLACK HILLS, SOUTH DAKOTA

D. M. Sheridan, H. G. Stephens, M. H. Staatz, and J. J. Norton
U. S. Geological Survey, Denver, Colo.; Menlo Park, Calif.; Denver, Colo.; Denver, Colo.

The Peerless pegmatite, one of the largest zoned pegmatites in the southern Black Hills, South Dakota, is 580 feet long and 360 feet wide at the surface. In cross section the pegmatite is anticlinal which suggests intrusion along two sets of fractures that strike N. 30° W. and dip 45° NE. and 45° SW.

The border and wall zones of the pegmatite consist of layers parallel to the contact that contain various proportions of quartz, plagioclase, muscovite, and perthite. Intermediate zones consist of cleavelandite-quartz-muscovite, perthite-cleavelandite-quartz, cleavelandite-quartz, and quartz-microcline pegmatite. The core of lithia mica-cleavelandite pegmatite is partly surrounded by a lithia mica-cleavelandite-quartz replacement unit.

The chief chemical components, as determined from modal analyses and estimated tonnage of pegmatite, are SiO_2 (77.0 per cent), Al_2O_3 (13.7 per cent), Na_2O (5.0 per cent), and K_2O (1.7 per cent). The SiO_2 content increases, and the Al_2O_3 content decreases inward from the contact. K_2O is chiefly in perthite- and muscovite-rich intermediate zones.

Repetition of layers in the border and wall zones indicates that the composition of the crystallizing fluid changed during early stages by addition or loss of material, or by failure of convection to main-

tain equilibrium. The inner zones are in the normal zonal sequence that suggests crystallization from a nearly closed system. The replacement unit indicates that at a late stage fluids escaped outward from the core and replaced previously crystallized pegmatite.

VARIATION OF COAL REFLECTANCE*

Raymond Siever
Illinois Geological Survey, Urbana, Ill.

Several thousand measurements of coal reflectance were made to study the variation of reflectance with rank, variation within and between vitrain bands, and variation related to the wave length of the incident light. Measurements were made of small areas of polished coal blocks under a metallurgical microscope using an electronic photometer (with photomultiplier) which permits a reproducible, objective estimate of the reflectance. The coals sampled varied from high volatile C through the entire range of bituminous coals and anthracites to meta-anthracite and "graphitized" coal. Statistical methods insured correct sampling design and proper analysis of results.

The reflectance measurements indicate that horizontal variation (parallel to banding) is negligible. In some bands vertical variation (normal to banding) is significant; the central portions of the bands are slightly higher than the borders. In many coals there is significant variation between vitrain bands. The range of variation between bands narrows with increasing rank to a minimum in the low-volatile coals. The variation between bands in any sample is not so great as that between coals of high- and medium-volatile, medium- and low-volatile, and low-volatile and anthracite rank. In some bands abnormal reflectance values may be due to the effects of included resinous material or to slight fusainization of vitrinite.

Increase in reflectance with rank is pronounced, as has been pointed out, but present data indicate a gradual, transitional increase rather than a discontinuous, stepwise progression.

PARAGENESIS AND STRUCTURE OF PITCHBLENDE-BEARING VEINS, CENTRAL CITY DISTRICT, GILPIN COUNTY, COLORADO

P. K. Sims
U. S. Geological Survey, Denver, Colo.

Substantial quantities of pitchblende have been produced from early Tertiary gold-, silver-, and sulfide-bearing quartz veins in the Central City District, within the mineral belt of the Front Range. The veins cut a complex mass of metasedimentary, metasomatic, and igneous rocks of Precambrian age and hypabyssal intrusive rocks of early Tertiary age. They are fissure fillings that formed at intermediate temperatures and pressures. Vein filling took place during three stages of mineralization.

The veins consist chiefly of quartz. Pyrite, sphalerite, and galena are the principal metallic minerals, and tennantite, chalcopyrite, enargite, and pitchblende are less abundant. The pitchblende typically is hard and lustrous and characteristically is colloform; locally it is soft and sooty. The pitchblende contains unusual quantities of zirconia and molybdenum. Pitchblende, the first metallic mineral to form, was deposited contemporaneously with quartz and was followed by pyrite, sphalerite, copper-bearing minerals, and galena. Fracturing and vein reopening followed pitchblende and pyrite deposition.

Pitchblende is present in only a few veins. It occurs locally along three of the five principal vein sets, in ore shoots or small lenses, and in pods that are separated by vein material essentially barren of uranium. The known ore shoots are small; the largest is about 50 feet high, 20 feet long, and averages a foot wide. Some of the shoots are systematically arranged within the veins, but others are erratically distributed.

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STRUCTURAL AND GEOMORPHIC EFFECTS OF THE DIXIE VALLEY-FAIRVIEW PEAK EARTHQUAKES OF DECEMBER 16, 1954, CHURCHILL COUNTY, NEVADA

David B. Slemmons
Department of Geology, Mackay School of Mines, University of Nevada, Reno, Nev.

On December 16, 1954, there were two severe earthquakes (7.2 and 6.8 Richter magnitude) with epicenters in the Dixie Valley-Fairview Peak area of Churchill County, Nevada. They were felt in six States and were accompanied by surface-fault displacements in a 60- by 20-mile zone.

There is up to 12 feet of right-lateral and about 20 feet of vertical movement. Lateral displacements of up to 9 feet and vertical displacements of more than 4 feet have occurred between near-by geodetic stations. Here, in a typical area of the Basin-Range Province, the horizontal displacements may equal or exceed the vertical. One graben valley was tilted, with displacements on the active faults bounding the two sides of the valley. Deformation decreases away from the faults. Reid's Elastic Rebound Theory explains part of the movement pattern.

The faults produced may be either simple fault planes occurring most commonly in bedrock, or zones made up of series of small-scale en echelon faults that developed in laterally strained alluvium, or step faults that are mainly caused by gravity slumpage within the soil above the main fault scarp, or graben zones that result from gravity slumpage in the hanging wall where the dip of the fault plane steepens as it approaches the earth's surface.

The earthquakes and fault displacements formed new or accentuated old scarps; created waterfalls and basins; offset ridges, streams, and roads; and caused numerous landslides, rock falls, and lurching features.

DEFLATION BASIN IN THE SECHURA DESERT OF NORTHERN PERU*

H. T. U. Smith
Geology Dept., University of Kansas, Lawrence, Kans.

A completely enclosed basin approximately 5.5 by 10 miles lies about 6 miles in from the coast of northern Peru, with its center approximately at Lat. 6°4′ S., and Long. 50°47′ W. The bottom of the basin is nearly flat, with extensive areas more than 60 feet below sea level; the deepest point is approximately 78 feet below sea level. The rim of the basin ranges from about 60 to 130 feet above the adjacent floor at most places, is generally abrupt, and is cut by numerous sharp though short gullies. The rock exposed around the basin consists of fine-grained sediments of Miocene age, mainly diatomaceous shale.

The general flatness of the strata exposed in the basin is adverse to interpretation as of tectonic origin. The several thousand feet of Tertiary rocks in the area is almost exclusively shale and sandstone and is not known to contain appreciable amounts of soluble rock, thus ruling out the possibility of solutional subsidence. Elimination of these other possibilities points to deflation as the probable mode of origin, and this is confirmed by (1) extensive eolian grooving, fluting, and streamlining on many of the small hills on the basin floor; (2) the high degree of susceptibility of the rock to eolian attack; and (3) the occurrence of numerous sand dunes in and around the basin.

OPTICAL PROPERTIES OF SOME LOW-TEMPERATURE PLAGIOCLASES

J. R. Smith
Geophysical Laboratory, 2801 Upton St., N. W., Washington, D. C.

Optical properties of 22 chemically analyzed samples of plagioclases from pegmatites, granites, stratiform mafic intrusions, and metamorphic rocks have been determined. For each sample, mean

* Based on research carried out under Office of Naval Research Contract Nonr-583(06)

values of the principal refractive indices were determined to a probable accuracy of ±0.0003; total birefringence to ±0.0001; and optic axial angle to ±0.3°. This accuracy is the result of (1) the precision of the techniques of measurement, and (2) averaging the optical properties of numerous grains from each sample to take into account the variation of composition of the plagioclase in each sample.

The variation of the measured optical properties with composition in the group of samples studied can be best represented by straight lines over limited composition ranges, with discontinuities between the straight-line segments at the approximate compositions An_{11}, An_{22}, An_{25-40}, An_{54}, An_{62}, and An_{88}.

UTILIZATION OF BUSINESS-MACHINE TABULATIONS FOR THE SYSTEMATIC CLASSIFICATION OF GEOLOGIC DATA*

William H. Smith and Russell A. Brant
Ohio Division of Geological Survey, Columbus, Ohio

In recent years two methods of punched-card cataloguing of geologic data have come into use. One utilizes the Keysort card which is usually punched and sorted by hand, and the other the business-machine card, which is punched and sorted mechanically and the data listed on form paper from type bars actuated by the punched card.

A system employing the use of business machines has been developed at the Ohio Geological Survey in connection with coal-resources studies. It provides a systematically organized summary and index of large volumes of geologic data which facilitates the mapping of economically or stratigraphically important strata and evaluation of mineral and fuel reserves.

The system utilizes number and letter symbols to classify the numerous items of geologic data and provides a convenient, time-saving device for making readily available the information essential in preparing reports concerning areal mapping, stratigraphic summaries, coal resources, and county or regional studies.

The various geologic, location, and identification data are coded by the geologist directly onto the stratigraphic record. The system of codes devised employs a primary code for stratigraphic position and a series of secondary codes to classify items of geologic significance regarding the key bed at a given locality together with thickness, sequence, and character of sediments in the interval upward to the next younger key bed. The coded information is then punched onto cards from which it may be sorted and listed mechanically in any arrangement convenient to the problem at hand.

STUDIES IN PARTICLE MORPHOGENESIS: (I) PEBBLES IN THE COLORADO RIVER FROM CENTRAL TEXAS TO THE GULF OF MEXICO

Edmund D. Sneed and Robert L. Folk
University of Texas, Austin, Texas

More than 2500 pebbles 32–64 mm long were collected along 270 miles of the Colorado River from source outcrops to the Gulf. Downstream the percentages of limestone and granite decrease rapidly, while chert and quartz increase equally. Limestone is so soft that it attains its maximum roundness within a very few miles, and thereafter undergoes no further change. Quartz rounds much more slowly but eventually reaches the same high limiting roundness as limestone. Chert, because it tends to spall, is everywhere much more angular than quartz although it does show a slight increase in roundness downstream.

It was thought that restricting pebbles to 32–64 mm would eliminate all effects of size on sphericity.

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* By permission of the Chief of the Division of Geological Survey, Ohio Department of Natural Resources

Unfortunately, however, even within this narrow range larger pebbles had lower sphericity than smaller ones ($\Delta\bar{x} = 0.03$, $P = .01$); pebble size thus controls sphericity more than transportation distance. Limestone, because of its bedding, remained at constant low sphericity (.55, $\sigma = .14$) throughout the entire distance. Quartz sphericity increased downstream independently of size, from .68 to .71 ($\sigma = .09$, $P = .02$). Chert surprisingly decreased in sphericity downstream, from .68 to .63 ($\sigma = .10$, $P = .001$). The fact that sphericity increased downstream for quartz, remained unchanged for limestone, and decreased for chert indicates that selective sorting is unimportant and that sphericity changes with transport are controlled by differential abrasional characteristics of the several rock types. All lithologies showed subequal proportions of disclike versus rodlike forms, with little change downstream; larger pebbles were more rodlike, indicating that size reduction takes place chiefly by wear of the longest diameter.

INTERPRETATION OF SHEETING

Arthur A. Socolow
Department of Geology, Boston University, Boston, Mass.

The term sheeting has been broadly applied to fractures which tend to be horizontal or parallel to the ground surface. Such fractures may be tensional or shear in origin. In many places the fractures which "tend to be horizontal" are actually gently dipping, slickensided surfaces; a shear origin is indicated in such cases.

Uniform removal of overburden over an extensive area does not satisfactorily account for sheeting. If the compressive stress of the overburden was not sufficient to cause fracturing when the load was at a maximum, the relief of stress by removal of overburden cannot be a more effective fracturing condition. During erosion, the compressive action of the overburden merely decreases; it does not reverse itself.

Any confining pressure decreases as overburden is removed; as long as the removal is uniform, the confining pressure will decrease equally in all directions. There would be no more tendency to expand laterally by relief of load than there is to compress laterally by uniform addition of load. Only where removal is not equal, as exemplified in quarries, the differential load may create horizontal compression sufficient to cause fracturing.

It is suggested that sheeting in many cases is actually due to regional horizontal compressive stresses of tectonic origin, unrelated to removal of overburden.

MINOR ELEMENTS IN THE ASH OF COALS FROM THE EASTERN REGION OF THE INTERIOR PROVINCE

Taisia Stadnichenko, Peter Zubovic, and Elizabeth L. Hufschmidt
U. S. Geological Survey, Washington, D. C.

Ash samples of more than 1000 blocks from over 60 columnar coal samples, from western Kentucky, Indiana, and Illinois, were analyzed for Ge by semiquantitative methods, mostly with phenylfluorone. An additional 14 elements (Be, B, Ti, V, Cr, Co, Ni, Mo, Cu, Zn, Ga, Sn, Y, and La) were determined spectrochemically in 250 selected blocks or in special coal samples with recognizable plant structures. The results of the analyses, presented in tables, are correlated with sedimentary characteristics of the coal samples or with the outstanding features of the plants which formed them.

Good Ge mineralization (0.1 to 0.26 per cent) has been found in the ash of coal from several beds in various localities of these States. Very high Zn (as much as 10 per cent) concentration in sedimentary ash was found in the northern part of Illinois and Indiana. The ash of several block samples contained high V (up to 4.2 per cent), Cr (up to 1.2 per cent), Mo (up to 0.15 per cent), and Be (0.03 per cent).

XENOLITHS IN PYROCLASTIC BRECCIA OF TRUK ISLANDS, WESTERN PACIFIC

John T. Stark and Richard L. Hay
U. S. Geological Survey, Washington, D. C.

The volcanic rocks of the Truk Islands in the Caroline Island group of the western Pacific consist largely of lava flows ranging in composition from nepheline basalt to soda trachyte, but pyroclastic breccia containing numerous xenoliths is extensively developed near a former crater on one of the islands. Fragments of soda trachyte and andesite, probably representing juvenile ejecta, are the most abundant constituents of the breccia, but xenoliths are locally common. The xenoliths consist of blocks of coarse-grained gabbro, blocks of lavas showing varying degrees of metamorphism, and fragments of tuffaceous limestone. Some of the gabbro blocks contain inclusions of pyroclastic rock and lava. A few of the gabbro blocks are cut by thin holocrystalline dikes composed of a hypabyssal (?) equivalent of soda trachyte. The texture of the gabbro suggests a deep-seated origin; the gabbro and metavolcanic inclusions may have been derived from the basement complex penetrated by the magma which built the Truk volcano, probably in late Tertiary time. The hypabyssal (?) dikes probably represent minor intrusions injected into the basement rock during the period of volcanism in Tertiary time.

COFFINITE, $U(SiO_4)_{1-x}(OH)_{4x}$, ITS WIDESPREAD OCCURRENCE IN UNOXIDIZED URANIUM ORES AND ITS PROPERTIES

T. W. Stern, L. R. Stieff, and A. M. Sherwood
U. S. Geological Survey, Washington, D. C.

The recently described mineral coffinite, a uranous silicate with $(OH)_4^{-4}$ substitution for $(SiO_4)^{-4}$, has been identified from more than 15 unoxidized uranium deposits in the sedimentary rocks of the Colorado Plateau province. Uraninite and coffinite are the most abundant uranium minerals in the unoxidized ores of this province. Coffinite has also been found associated with uraninite in the Copper King mine, Larimer County, Colorado (a vein deposit), and with carbonaceous pellets from sediments in Texas and Oklahoma.

On the Colorado Plateau, coffinite occurs chiefly associated with organic material, and to a lesser extent disseminated in sandstone. It is associated with uraninite and low-valence vanadium minerals. Superficially, coffinite resembles high-rank coal and is very fine-grained. Coffinite is tetragonal ($a_0 = 6.94A$; $c_0 = 6.31A$) and is isostructural with zircon ($ZrSiO_4$) and thorite ($ThSiO_4$). Because of its fine grain and association with uraninite and low-valence vanadium minerals, coffinite could not be completely purified. Oxidation-potential measurements on a suspension of coffinite in $1N$ H_2SO_4 show that most of the uranium is in the quadrivalent state. From 46.37 to 68.29 per cent UO_2 and from 5.20 to 8.50 per cent SiO_2 are present in carefully selected and concentrated materials. If we assume the composition $USiO_4$, there is insufficient silica. Infrared analyses on coffinite demonstrate existence of hydroxyl bonds as well as silicon-oxygen bonds. The silica deficiency is thought to be compensated by hydroxyl substitution. Attempts to synthesize coffinite have been unsuccessful. The proposed formula is $U(SiO_4)_{1-x}(OH)_{4x}$.

INTERPRETATION OF THE $Pb^{206}/U^{238} < Pb^{207}/U^{235} << Pb^{207}/Pb^{206}$ AGE SEQUENCE OF URANIUM ORES

L. R. Stieff and T. W. Stern
U. S. Geological Survey, Washington, D. C.

Many of the recently published age determinations on uranium ores have shown the following anomalous age sequence: $Pb^{206}/U^{238} < Pb^{207}/U^{235} << Pb^{207}/Pb^{206}$. Various investigators have selected one of the three ages as most nearly approximating the "true age" of the ore. They have

proposed several hypotheses to support these selections: loss of radon, loss of lead, presence of original radiogenic lead, and reworking or multiple periods of uranium deposition.

None of these hypotheses has been satisfactorily established by systematic geologic investigations or thoroughly tested by independent geologic evidence. In addition, the agreement between Pb^{206}/Pb^{210} and Pb^{206}/U^{238} ages of uranium ores with much higher Pb^{207}/Pb^{206} ages strongly suggests that radon loss is not the major factor in these anomalous age sequences. The loss-of-lead hypothesis cannot account for Pb^{207}/Pb^{206} ages appreciably in excess of the "best" independent estimates of the age of the related uranium ores or the enclosing rocks. Some investigators believe that the original radiogenic lead hypothesis does not account for the observed differences in the radiogenic lead content of the galena within uraninite specimens and the free galena in the same deposits. Single age determinations on complex uranium ores representing two or more periods of deposition should not be reported.

One of the most pressing problems in geochronology is to establish the geologic process or processes resulting in the $Pb^{206}/U^{238} < Pb^{207}/U^{235} << Pb^{207}/Pb^{206}$ age sequence. Until this problem has been clarified, caution should be used in selecting one age from the sequence and assuming the geologic processes when the necessary geologic, mineralogic, and analytical data are not available.

PREREQUISITES FOR THE GRADUATE CURRICULUM IN GEOLOGY

Paris B Stockdale
Department of Geology-Geography, University of Tennessee, Knoxville, Tenn.

In setting forth prerequisites for the graduate curriculum in geology, as well as the nature of such a curriculum, one must first decide upon the objectives of the graduate program. Sharp differences of opinion arise as to whether the aims should be the immediate specialization in some limited field of geology, or whether they should be the completion and strengthening of the broad basic fields in geology, started in the undergraduate curriculum. Much of an undergraduate program must be taken up with subjects other than geology because of the necessity for basic training in background sciences, such as chemistry, physics, mathematics, and biology, to say nothing about requirements in the languages, other humanities, and the social studies. As a consequence the basic branches of geology cannot all be covered in the undergraduate curriculum. Therefore, at least a fifth year is needed to give the broad grounding which in turn is prerequisite to further graduate study leading to specialization. The view here taken is, therefore, that the Masters degree program (or its equivalent) should not be highly specialized—that broad, basic training is first desired, and that such training normally calls for at least 5 years of study. It is then that the prerequisites for a Doctoral program of specialization are best satisfied, and at the same time the student is best prepared for the many opportunities that may be available to him should he not pursue further graduate study.

MAPPING CHANNELS IN THE SALT WASH AND SHINARUMP OF THE COLORADO PLATEAU

Wm. Lee Stokes
Dept. of Geology, University of Utah, Salt Lake City, Utah

The "channel" theory of uranium deposition is one of several explanations for ore deposits in the continental formations of the Colorado Plateau. The theory rests on the observation that most sedimentary uranium deposits lie within porous sand bodies representing ancient river channels and appear to have been localized by sedimentary features produced by river action.

The channel sandstones and associated sediments are complex and show deposition by streams of all sizes in both flood and low stages with consequent variation in size of channels, sorting and composition of constituents, types of primary structures, and continuity of lithologic units.

Mapping of channels involves difficult problems of selection, recording, and interpretation of data.

Methods are not yet standardized. A typical project involves selection of base map, arbitrary selection of features to be mapped and recorded, amount of territory to be covered, and projection of observed features into covered territory. Several studies in the Salt Wash sandstone and Shinarump conglomerate are described.

Aside from academic interest the mapping of channels has been useful in detecting trends or belts of mineralization, possible extensions of known mineralized areas, and in laying out programs of exploration. Evidence seems conclusive that, whatever may have been the ultimate origin of the constituents of the radioactive minerals, their final sites of deposition were determined in most cases by sedimentary features.

NEW DATA FROM WESTERN NEBRASKA REGARDING PLEISTOCENE CLASSIFICATION

Thompson M. Stout
Department of Geology, University of Nebraska, and University of Nebraska State Museum, Lincoln, Nebr.

New evidence from western Nebraska, particularly from Chase and Brule canyons near Brule and Lewellen, seems important. These and other "hanging" valleys indicate major northwest-southeast drainages (T^5) in the Early Pleistocene, following tilting of Ogallala (including its capping caliche soil and limestones).

The valley fills consist of: (1) basal gravel (Holdrege = Lower Broadwater = Nebraskan outwash); (2) intermediate marl-peat with soil (new, eroded) and Loessic silts (all Lisco = Fullerton = Aftonian to Kansan); and (3) upper gravel (Red Cloud = Upper Broadwater = Kansan outwash). After *abandonment* (and T^4 cutting) the following were deposited: (4) colluvial-loessic silts (new), greatly modified by (5) *deep soil profile* (new = true Yarmouth soil). *Erosion* was followed by: (6) Sappa loess; modified by (7) *prominent soil* profile (new = post-Sappa, so-called "Late Yarmouth" soil). *Erosion* was again followed by (8) "Pearlette" ashy silts and Loveland loess, with same soils as at Buzzard's Roost and Eustis that may correlate with Illinoian moraines; (9) Sangamon-Farmdale complex profile, eroded in places; (10) very thick Peorian loess; (11) Brady soil; and (12–14) Bignell loesses with soils.

Unit (5) may evidence a true interglacial, completing Fifth *double* terrace fill, with Aftonian possibly an *interstadial*. Similarly, each of the later terrace fills (T^4-T^0) is double, suggesting a basic pattern of two-phase (diminishing?) glaciations during the Pleistocene, including a double Illinoian complex. A new group name for each terrace fill seems essential.

ACCELERATED LAND EROSION AS A DRAINAGE-DENSITY TRANSFORMATION

Arthur N. Strahler
Department of Geology, Columbia University, New York, N. Y.

Fundamental concepts of open systems and steady states can provide in terms of total drainage-basin morphology and dynamics a unified explanation of accelerated land erosion. Severe erosion, beginning with gullying and ending in formation of badlands, may be viewed as a drainage-density increase attending an upset of the established steady state of geologically normal drainage-basin operation. Badlands represent a new steady state of erosion established on unit basins of greatly reduced linear scale.

Drainage density may be considered a function of slope, local relief, runoff intensity, and Horton's erosion proportionality factor, which measures susceptibility of the ground surface to erosion. These variables can be expressed in two dimensionless groups: (1) a product of drainage density and relief, divided by slope, summarizes geometry of the system; (2) a product of runoff intensity and surface susceptibility summarizes process. When a steady state of erosion exists, the drainage-basin geometry, expressed by a particular combination of drainage density, slope, and local relief, is adjusted to prevailing values of runoff intensity and surface susceptibility.

Severe erosion, accompanying radical changes of ground surface, is caused by increase of runoff intensity or susceptibility. Morphological adjustment consists of ramification of the channel network into gully systems, thus not only greatly increasing drainage density, but also steepening both the valley-side slopes and channel gradients and reducing the local relief between channel and adjacent divide. Thus modified, the system is adapted to a much higher intensity of surface denudation and sediment export.

REVISION OF A. W. GRABAU'S SPECIES OF *MUCROSPIRIFER* FROM THE DEVONIAN TRAVERSE GROUP OF MICHIGAN

Erwin C. Stumm
Museum of Paleontology, University of Michigan, Ann Arbor, Mich.

In an advance print of the proceedings of the Seventh International Zoological Congress, 1907, A. W. Grabau named a new species and four new varieties of the common Devonian brachiopod genus *Mucrospirifer* from the Traverse group of Michigan. A short descriptive sentence accompanied each name. In 1915 C. C. Mook, at that time a student conducting research under Grabau's direction, published a statistical study in which he introduced an additional species accredited to Grabau and gave more extended descriptions to Grabau's species and varieties, referring to all of them as mutations. The lack of illustrations and abridged descriptions have made these species unusable as index fossils for the different formations of the Traverse group. The types of these species are in the collections of the Museum of Paleontology of the University of Michigan. They are illustrated and described in detail in this report. The species show an interesting evolutionary sequence and make excellent index fossils to distinguish the various formations of the Traverse group.

CRYSTAL STRUCTURE OF VONSENITE

Y. Takeuchi
The Pennsylvania State University, University Park, Pa.

The crystal structure of ludwigite has been determined independently by Takeuchi *et al.* (1950) and Bertaut (1950). However, since the boron-atom position was not definitely fixed by the ludwigite analysis, the structure determination of vonsenite (iron-rich ludwigite) was undertaken in order to obtain the boron configuration accurately. The orthorhombic cell of vonsenite (space group Pbam) has the dimensions

$$a = 9.37_0 \quad b = 12.35_7 \quad c = 3.05_5 \text{ A}$$

F^2 (hkO) data were obtained from a c axis Weissenberg photograph using multiple film technique.

Successive (F_{obs}-F_{fe}) electron-density maps and (F_{obs}-F_{calc}) Fourier syntheses showed the boron atoms very clearly and resulted in a final agreement factor, $R = \Sigma \,||F_o| - |F_c||/\Sigma\,|F_o|$, of 0.08 for the (hkO) projection. The triangle of oxygen atoms surrounding the boron atom with B-O distances of 1.39 ± 0.03 A was found to be slightly distorted. The final set of atomic co-ordinates is as follows:

	x/a	*y/b*	*z/c*		*x/a*	*y/b*	*z/c*
Fe(Mg)1	0	0	½	02	0.114	0.146	½
Fe(Mg)2	½	0	0	03	0.125	0.375	0
Fe(Mg)3	−0.001	0.277	½	04	0.384	0.085	½
Fe^{+3}	0.247	0.144	0	05	0.350	0.260	0
01	0.160	−0 045	0	B	0.271	0.355	0

PINE MOUNTAIN FAULT—THRUST OR SLIDE?

Hall Taylor
Dept. of Geology, Columbia University, New York, N. Y.

Low-angle faults, which in places are almost horizontal, cut Paleozoic strata throughout much of the southern Appalachian region. Along one such structure, the Pine Mountain fault extending more than 100 miles from southwestern Virginia across southeastern Kentucky and into northeastern Tennessee, lower and middle Paleozoic beds have overridden underlying formations and have moved in places at least 9 or 10 miles northwestward. Thrusting caused by tangential pressure originating in the more highly deformed area to the southeast has commonly been ascribed as the cause of the movement.

In recent years work in South America, Europe, and elsewhere has suggested that blocks of the earth's crust with areas measured in square miles may slide horizontally for miles as unbroken units across the earth's surface because of forces resulting from gravity.

It appears that a comparatively small uplift of the area southeast of the Pine Mountain fault may have caused gravitational sliding of a large block of the earth's crust northwestward, and it is suggested that such sliding, rather than the more conventional thrust faulting, may be at least in part responsible for the Pine Mountain fault structure.

GLACIAL FACIES WITHIN THE DES MOINES LOBE, CENTRAL IOWA

L. A. Thomas and K. M. Hussey
Iowa State College, Ames, Iowa

Within the Wisconsin drift along the margin of the Des Moines lobe are some buried lenticular bodies of fossiliferous silt and silt interlayered with sand and gravel, whose widespread occurrence has not been reported previously. Some of these silts have been called loess and have been assigned an age varying from Iowan to Tazewell. Gastropods (terrestrial and aquatic), ostracods, pelecypods, and plant remains are abundant. The fossils suggest an age not older than Tazewell.

Contacts of these buried bodies with the overlying till are of two types: (1) the silt or sand imperceptibly decreases through an interval of 2–3 feet as the pebbles of the till increase; (2) a transition is effected by a series of thin interbeds of silt, sand or gravel, and till. Fossils may extend across the boundary 2–10 feet into the till.

The environments of accumulations and the agents of deposition are varied. These include proglacial bog fillings, outwash fluvial terraces, mudflows, and perhaps eolian deposits; however, eolian origin cannot be demonstrated conclusively. Times of accumulation range from the advancing through the decaying stages of glaciation. It is concluded that these deposits are facies of glacial deposition and that most of them are closely allied (temporally) with the overlying drift of Cary subage.

MINERALOGY OF THE PEANUT MINE, MONTROSE COUNTY, COLORADO

Mary E. Thompson and Carl H. Roach
U. S. Geological Survey, Grand Junction, Colo.

The vanadium-uranium ore in the Peanut mine, Bull Canyon mining district, Montrose County, Colorado, occurs in the Salt Wash sandstone member of the Morrison formation (upper Jurassic). The ore bodies are relatively small, but grouped in clusters; they are enclosed in the upper parts of festoon cross-lamination structures. The festoon surfaces are relatively impermeable to ground water, and small perched water tables saturate most of the ore bodies.

Most of the ore is unoxidized because oxidation has been inhibited by stagnant ground water of the perched water tables. The parts of the ore bodies above the water table show a vertical zoning of oxidation products; the upper parts are the most oxidized.

Primary ore minerals are uraninite, coffinite, montroseite, and vanadiferous clays. The first oxidation products of the primary ore are paramontroseite and three new vanadium (IV) minerals. Melanovanadite, two new vanadyl vanadates, and corvusite are formed next. Tyuyamunite and pascoite are the only highly oxidized minerals found in the deposit.

Metallic minerals associated with the ore are marcasite, pyrite, chalcopyrite, chalcocite, digenite, galena, sphalerite, molybdenite, and native selenium.

Barite, pyrite, and montroseite commonly occur together with coalified wood. Limonite and malachite and a possible calcium selenate are associated with the oxidized parts of ore bodies.

ENGINEERING PROBLEMS ASSOCIATED WITH WEATHERED LIMESTONE

T. H. Thornburn and Don U. Deere
Talbot Laboratory, University of Illinois, Urbana, Ill.

The difficulties associated with the design and construction of dams and reservoirs in areas of cavernous limestone rocks have become generally known through publications of the TVA. However, other types of engineering problems associated with weathered limestone are not so well recognized.

Of primary concern in the construction of highways, air fields, foundations of light structures, or tunnels are the engineering properties of the residual soil and the character of the contact between the soil and the limestone. On the other hand, the presence of solution cavities and the properties of their fillings are of importance in the design and construction of heavy structures.

A summary of physical soil constants including Atterberg limits, natural water contents, compaction data, and textural classification is given for typical limestone soils in central United States and Puerto Rico. These data have been obtained primarily from various highway organizations. The clay mineralogy and activity have been determined for representative samples. Highway performance can be correlated with these soil properties.

Test pits sunk during preliminary exploration for a tunnel at Chattanooga, Tennessee, penetrated as much as 25 feet of residual soil developed over Chicamauga limestone and Knox dolomite without encountering sound rock. Physical soil constants and strength characteristics of the residuum are shown.

Case histories of building-foundation problems in areas of weathered limestone in Iowa, Illinois, and Puerto Rico are discussed.

GEOMORPHIC HISTORY OF THE UPPER WABASH VALLEY*

William D. Thornbury
Department of Geology, Indiana University, Bloomington, Ind.

The preglacial Wabash River was much shorter than the present river. Most of the area now drained by the upper Wabash was tributary in Tertiary time to the master stream of eastern North America, the Teays. Burial of the Teays Valley in Indiana may have been initiated by Nebraskan glaciation, but it was mainly effected by later glaciations, and portions of this valley served as drainageways as late as the Tazewell subage. Integration of Teays drainage with the preglacial Wabash to form the present Wabash River began during the Kansan glaciation.

The upper Wabash Valley roughly parallels the Teays Valley across Indiana, but it is superposed on glacial drift across a Tertiary topography and as a result is narrow where it is cut through preglacial bedrock uplands and wide through partially resurrected Tertiary valleys. Exhumed Silurian bioherms are striking features along one bedrock segment, and miniature scabland topography characterizes several of the bedrock stretches.

Gravel terraces attest to the importance of the Wabash Valley as a Wisconsin sluiceway. One of the

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two persistent terraces represents the upper limits of valley filling; the other is a planation surface cut by overflow waters from Lake Maumee.

Bluffs along the Wabash and its tributaries expose multiple Wisconsin tills, as well as the Farmdale, Iowan, and Tazewell loesses. Loess of Cary age is local.

Maps of the bedrock topography indicate an extensive buried Tertiary peneplain believed to correlate with the Lexington and Highland Rim peneplains of Kentucky and Tennessee.

HETEROGENEOUS DISTRIBUTION OF URANIUM, THORIUM, AND LEAD IN MONAZITE CRYSTALS

G. R. Tilton and L. O. Nicolaysen
Department of Terrestrial Magnetism and Geophysical Laboratory, Carnegie Institution of Washington, Washington, D. C.

The results of four age determinations on monazites are as follows:

Locality	Age in Millions of Years U^{238}/Pb^{206}	U^{235}/Pb^{207}	Pb^{207}/Pb^{206}	Th^{232}/Pb^{208}
Goodhouse, S. Africa	930	915	880	900
Houtenbek, S. Africa	1400	1230	930	940
Steenkampskraal, S. Africa	1080	*	*	990
Brown Derby Mine, Colo.	1590	1420	1170	995

The ground-up samples have been washed for 15 minutes in cold 6M hydrochloric acid, and the compositions of the acid-soluble materials compared against those of the total samples. In general, the acid washing removed a few per cent of the uranium, thorium, and lead from the crystals.

Monazite	Fraction	Pb^{206}/Pb^{204}	Pb^{207}/Pb^{204}	Pb^{208}/Pb^{204}	Th/U
Goodhouse	Total Sample	530	50.2	6100	38.8
	Acid Soluble	189	26.7	1640	31.6
Houtenbek	Total Sample	924	78.3	4610	24.6
	Acid Soluble	7000	526	1530	6.0
Brown Derby	Total Sample	1010	92.9	6660	34.8
	Acid Soluble	82.3	18.4	185	19.2

These data demonstrate an inhomogeneous distribution of uranium, thorium, and the radiogenic leads derived from uranium and thorium. This effect is more pronounced at Houtenbek and Brown Derby than at Goodhouse. All samples show inhomogeneities in the distribution of primary and radiogenic lead. Such acid-washing experiments provide an important method for evaluating these age determinations.

URANIUM CONTENT OF WATER IN THE GREAT PLAINS REGION OF NEBRASKA AND IN ADJACENT STATES

Harry A. Tourtelot
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Strata of Tertiary age in south-central South Dakota, western Nebraska, and northeastern Colorado are not known to contain uranium deposits, yet waters derived from the strata have a higher uranium content than reported for waters in other nonuranium-bearing terranes. Samples from eight wells and springs contained 4 to 110 parts per billion uranium. Eleven samples from eight streams contained 3 to 33 parts per billion uranium. The uranium content of the waters is believed

* Primary lead correction too high for an accurate age.

to be related to the uranium content of tuffaceous rocks of Oligocene, Miocene, and Pliocene age that are the sources for the waters sampled.

Samples of highly alkaline water from lakes in western Nebraska contained 12 to 100 parts per billion uranium, and samples of ground water from wells adjacent to the lakes contained less than 5 parts per billion. The lakes are concentrated solutions resulting from evaporation of ground water; the pH of the lake water ranges from about 8 to 10. Solubility of uranium at this high pH undoubtedly results from complexing with carbonate in the lake water. Sodium, potassium, and bicarbonate, carbonate, and sulfate ions are enriched in the lake waters to a greater extent than is uranium. Semiquantitative spectrographic analyses indicate that calcium, magnesium, aluminum, silicon, lithium, titanium, vanadium, chromium, manganese, iron, copper, strontium, and barium are depleted in the alkaline waters compared to the ground water, probably by precipitation because of the high pH and associated scavenging of some of the elements.

MINERALOGY AND GEOCHEMISTRY OF THE URANIUM DEPOSITS IN THE WHITE CANYON AREA, SAN JUAN COUNTY, UTAH*

Albert F. Trites, Jr.
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Uranium deposits in the White Canyon area, San Juan County, Utah, occur in channels cut into beds of the Moenkopi formation of Early Triassic age and that have been filled by sediments of the Shinarump conglomerate of Late Triassic age. The most favorable beds are sandstone and conglomerate interbedded with siltstone that contain abundant carbonized wood and clay seams.

The ore deposits are generally classified as the copper-uranium type and contain pyrite, chalcopyrite, uraninite, bornite, sphalerite, and galena, in order of abundance. Uraninite, pyrite, and bornite have been deposited principally as replacement of organic material, chalcopyrite as disseminations in sandstone and replacement of wood, sphalerite as filling of fractures, and galena as fillings of cavities. Uranium, copper, iron, arsenic, barium, cobalt, molybdenum, nickel, lead, zinc, and magnesium apparently have been added to the Shinarump conglomerate by the mineralizing solutions.

Oxidation of the ore bodies exposed at the rim of Shinarump conglomerate has produced an oxide zone which grades through a transition zone into the sulfide ore. Uranium, copper, and possibly iron have been secondarily enriched by solution in the oxidized zone and inward movement and redeposition in the transition and sulfide zones. The secondary uranium and iron have migrated farther inward than the copper and have been deposited as sooty pitchblende and marcasite, respectively. The copper has been concentrated as the supergene sulfide minerals chalcocite and covellite and as hydrous sulfates and carbonates.

GEOCHEMISTRY OF STRONTIUM

Karl K. Turekian
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

The geochemistry of strontium has been investigated with special emphasis on attaining accurate values for crustal abundances by considering the problems of analytical technique and representative sampling.

The difference in behavior of Sr relative to Ca in granitic as compared to basaltic rocks is striking. This is illustrated by a granitic batholith (Coast Range) in which the Sr content increases with Ca content as contrasted with the Stillwater complex (a mafic body) in which the progressively less calcic layers show increase in strontium.

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* Approved for publication by the Director, U. S. Geol. Survey, and by the U. S. Atomic Energy Commission

For the crust as a whole granites retain the geochemical coherence of strontium with calcium, but the basaltic rocks show no correlation.

Abundance of strontium in the crust

Rock	Avg. % Calcium	Avg. ppm Strontium	$\frac{\%\ Sr}{\%\ Ca} \times 10^3$
Basaltic Rocks (245)	7.1	465	6.5
Granitic Rocks (175)			
0.1–1.0% Ca	0.6	95	16.0
1.0–5.0% Ca	1.9	440	22.5
Sedimentary Rocks			
Limestone (150)	40	610	1.5
"Average" Shale (69)	5.0	300	6.0

If it is assumed that the crust is mainly basaltic and granodioritic the crustal abundance of strontium becomes 450 ppm.

The high ratio of Sr/Ca in granitic and granodioritic rocks when compared with the low ratio in sedimentary rocks precludes the possibility that the main source of sedimentation has been from these igneous rock types at least since the Cambrian. The basaltic component must be strong if not dominant. Finally it is concluded that the Sr/Ca ratto in sea water must be increasing with time.

CLASSIFICATION OF GRANITES, SYENITES, AND NEPHELINE SYENITES

O. F. Tuttle
The Pennsylvania State University, University Park, Pa.

Experimental studies have demonstrated that at high temperatures there is complete solid solution between the alkali feldspars whereas at low temperatures there is little mutual solubility. This fact permits classification of these rocks into two groups, I hypersolvus, and II subsolvus. Goup II rocks are classified according to composition of the potash feldspar which is a function of temperature of final crystallization. Three groups are used: II A, rocks in which the potash feldspar contains >30% soda feldspar in solid solution or intimate intergrowth, II B, >15% and <30%, and II C, <15% soda feldspar in the potash feldspar. These four groups of plutonic rocks may be further subdivided according to the nature of the potash feldspar which usually consists of two or more constituents in intimate intergrowth (perthitic). There are generally (1) sanidine, (2) orthoclase, or (3) microcline, although if possible the nature of the perthite should be determined. For example, orthoclase may be optically intermediate between sanidine and orthoclase and may be an x-ray perthite consisting of high albite, low albite, and monoclinic potash feldspar.

Only those rocks having 80% or more normative Q + ab + or + ne + lc + kp, constituents of "petrogeny's residua system" (Bowen, 1937), are considered in this classification.

Rocks formed by low-temperature granitization processes will always fall in group II C, whereas rocks in groups I and II A have formed at high temperatures and are undoubtedly magmatic. Magmatic granites, syenites, and nepheline syenites may of course have their feldspars recrystallized during cooling or by subsequent metamorphism and thereby fall in group II B or II C.

HOW GEOLOGY TEACHES THE STRUCTURE OF MATTER

Sherwood D. Tuttle
State University of Iowa, Iowa City, Iowa

In this atomic age students in courses in elementary geology can begin to understand the structure of matter through the study of minerals. Atomic lattices and bonding have meaning and significance when related to the crystal forms and cleavage habits of common minerals. These characteristics, plus atomic radii, weights, and packing explain differences in specific gravity, mineral structures, and hardness, as well as other physical properties.

WALL-ROCK ALTERATION AS A GUIDE TO CARNOTITE DEPOSITS AND THEIR ORIGIN, NORTHERN BLACK HILLS, SOUTH DAKOTA

R. C. Vickers
U. S. Geological Survey, University of Wisconsin, Madison, Wis.

Several carnotite deposits are present in the Fall River sandstone of Lower Cretaceous age on the north flank of the Black Hills, Butte County, South Dakota. The deposits are in a fine-grained, well-sorted, persistent basal sandstone unit that ranges in thickness from 2 to 18 feet and dips about 4° NE.

Detailed mapping of the basal sandstone shows that all the known carnotite deposits and most of the areas of high radioactivity occur where the sandstone changes from reddish on the up-dip side to normal yellowish gray or buff down dip. Radioactivity measurements in the field show that uranium is concentrated continuously along the sinuous red to buff contact for a known distance of at least 5 miles. Laboratory work indicates that the red color is not a function of the total iron present but is probably due to the alteration of hydrous ferric oxides of hematite.

The close association between uranium deposits and the red to buff color contact suggests that the two were formed by the same solutions. If so, the uranium was probably deposited from ground water that moved down dip and changed from oxidizing to mildly reducing. Concentrations of uranium have resulted from the localization of reducing conditions, caused perhaps by structures superimposed on the regional dip, local thinning or decrease in permeability of the sandstone, or concentrations of carbonaceous materials.

DEEP-CHANNEL AND ALLUVIAL FILL ALONG THE KENTUCKY SECTION OF THE OHIO VALLEY

Eugene H. Walker
U. S. Geological Survey, Iowa City, Iowa

A strong profile based on data from wells and test borings shows that the buried pre-Illinoian channel of the Ohio River descends from 472 to 165 feet above sea level in the 660 river miles from Ashland, Kentucky, to the Mississippi River at Cairo, Illinois. The buried channel lies 25 feet deeper than the present river level at Ashland, 110 feet deeper at Cairo.

The alluvium consists of a thick sheet of sand and gravel, overlain by a thinner sheet of fine-grained material, dominantly silt and containing some sand and clay. The original maximum thickness of the alluvium increased from 130 feet at Ashland to 180 feet at Cairo.

The sheet of sand and gravel is considered to be the Wisconsin valley train, mostly deposited in late Tazewell time. Pre-Wisconsin alluvium was largely removed when the valley was scoured out to the old bedrock floor in late Illinoian or early Wisconsin time.

The upper, fine-grained material is considered to have been deposited in the rising, slack water produced along the Ohio by the rise of water levels that continued along the Mississippi River long after meltwater had ceased to run in the Ohio basin.

The coarse-grained alluvium forms an aquifer of great capacity and great importance to the region it traverses. Very large sustained supplies of ground water can be developed at properly chosen sites where pumping causes water-level gradients that induce water to flow from river bed into permeable alluvium.

SEDIMENT CORES FROM THE GULF OF MEXICO

K. K. Wang and David B. Ericson
Lamont Geological Observatory, Palisades, N. Y.

Analyses of many cores taken throughout the Gulf of Mexico show a marked difference between the fauna at the top of the cores and the fauna below. The top fauna averages about half a meter thick, although a maximum of 4 meters with only minor breaks is recorded. Forms most significant in the top fauna are the planktonic Foraminifera: *Globorotalia menardii*, *Globorotalia tumida*, *Globorotalia truncatulinoides*, *Globigerina ruber*, *Globigerina eggeri*, *Globigerina sacculifer*, *Pulleniatina obliquiloculata*, and *Orbulina universa*.

Zoning of the fauna in most cores is impossible because of the great decrease in total population at depth, but a few cores show the repeated recurrence of the top fauna at depth. This phenomenon is similar to the faunal zones found in the sections deposited along the path of the current system in the Atlantic.

Although there is no proof that the sediments were deposited during the Pleistocene epoch, there is strong evidence on the basis of the vertical distribution of the cold- and warm-water fauna that the sediments below the top fauna differ from the sediments being deposited during the Recent epoch.

The change in fauna is also in most cases marked by a grain-size change in the sediments. Layers of silts are usually found below the top faunal zone, while the sediments of the top faunal zone usually consist of fine lutite particles.

PENNSYLVANIAN ROCKS OF ARIZONA AND BORDERING AREAS

Harold R. Wanless
University of Illinois, Urbana, Ill.

Field studies of 27 Pennsylvanian columns in Arizona, 6 in western New Mexico, 5 in southwestern Colorado, 1 in southeastern Utah, and 4 in southern Nevada show a maximum thickness of 2500 feet. The strata are called Naco in Arizona, Magdalena in New Mexico, Molas, Hermosa, and Rico in Colorado, and Utah and Bird Spring in Nevada. The succession is predominantly limestone in western New Mexico, southeastern Arizona, southeastern Utah and southern Nevada. In central and northern Arizona there is intertonguing with red clastics of the Supai delta, and in southwestern Colorado the section is predominantly clastic with occasional marine limestones. Fusulinid faunas are present in all areas except northern Arizona. They represent the zones of *Fusulinella* (Lampasan or Atokan), *Fusulina* and *Wedekindellina* (Des Moines), *Triticites* (Missouri and Virgil), and *Schwagerina* (Wolfcamp Permian).

A broad tongue of siltstone and fine sandstone, the Supai delta, extends from the Grand Canyon southwestward and divides the area into two marine basins. In the basin southeast of this delta marine limestones are progressively truncated by delta sediments, so that the youngest fusulinid faunas are of Wolfcamp age in southeastern Arizona and successively of Virgil, Missouri, and Des Moines age northward to Fossil Springs, central Arizona, where the only limestone present is of Early Des Moines age. No fusulinid faunas are found in the Grand Canyon area. They are known to be present but have not yet been studied in exposures along Lake Mead. A full succession from *Fusulinella to Schwagerina* is found in southern Nevada.

RATES OF MASS WASTING

A. L. Washburn
Department of Geology, Dartmouth College, Hanover, N. H.

Quantitative studies of rates of mass wasting are almost lacking with respect to slow-movement types such as creep, including solifluction. This is in contrast to the availability of data on rates of stream flow and glacier movement, yet these mass-wasting processes are areally the more important. It is therefore suggested that instrumental determinations of rates of mass wasting, particularly of the slow-movement types, as related to process, terrain and vegetation, material and its water content, and climate and season should be undertaken in a variety of regions to obtain information on the mechanics, regimen, and quantitative significance of the processes.

With respect to solifluction, for instance, Wilhelm Dege reported a rate as high as 13 cm a day on a 6-degree slope in Svalbard; the total observed movement during a 3-day rainy period in August is from 2 to 19 cm. Measurements by the author on a 12-degree slope on Victoria Island in the Canadian Arctic indicated a movement of 4 cm between the middle of June and middle of July, and an additional movement of half a centimeter from then until the following January, making a total of 4½ cm in 6 months. Obviously rates of solifluction and of other mass-wasting processes depend on a number of variable factors. Further work, which will emphasize instrumental determinations of rates of mass wasting and its variables in an arctic environment, is being undertaken in East Greenland.

RELATIVE AGES OF EASTERN MASSACHUSETTS GRANITES BY TOTAL LEAD RATIOS IN ZIRCON

G. R. Webber, P. M. Hurley and H. W. Fairbairn
Massachusetts Institute of Technology, Cambridge, Mass.

The relative lead content of a number of accessory zircon samples separated from eastern Massachusetts granites was determined spectrographically. Selected samples were analyzed for absolute lead content by C. L. Waring of the U. S. Geological Survey, and these provided a calibration for the remainder. Contents of uranium and thorium were determined by scintillation spectrometer, and the values for total alpha activity calculated from these were checked by total alpha count. The average ratio of thorium to uranium was such that 85 per cent of the radiogenic lead was derived from uranium.

If Waring's calibration values are correct, the lead ratios show two principal ages for the granites as follows:

250 MY: Localities near Peabody, Rockport, and Cape Ann; north of North Attleboro; north end of Whitinsville; near Fitchburg.

360 MY: Localities northeast of Milford and east of Wrentham.

The geological relationships suggest that probably the granites north and south of Boston known as the Quincy type, as well as part of the area mapped as Dedham granodiorite, and some of the granites extending southward into Connecticut, are all approximately 250 MY. At least one area of granite mapped as Dedham granodiorite was intruded earlier, at 360 MY.

OXIDATION OF THE COLORADO PLATEAU ORES AND ITS RELATION TO RECENT GEOLOGIC HISTORY

Alice D. Weeks
U. S. Geological Survey, Washington, D. C.

Oxidation studies are helping to clarify the problem of origin of the Colorado Plateau uranium deposits by eliminating from consideration those features formed during oxidation and the modifications made by recent ground water.

Geologic, mineralogic, and chemical evidence indicates that the carnotite ores on the Plateau have been derived by progressive oxidation of primary, black ores. The classification of Plateau ores on the basis of association of vanadium with the uranium is important because during oxidation vanadium complexes all available uranium and effectively holds it in carnotite, a stable, secondary mineral. This permits the accumulation of large oxidized vanadiferous deposits at shallow depth. Only in the caliche zone at or close to the surface of the ground is carnotite being leached. In the absence of vanadium, unstable oxidized products such as uranyl carbonates and sulfates develop around uraninite. These are removed soon after they form, thus reducing the possibility of large oxidized, nonvanadiferous deposits in the Plateau. In exploration for nonvanadiferous ores, one should consider conditions favorable for ore preservation along with other factors of favorability.

No significant secondary enrichment occurs in vanadiferous uranium ores. Only in a few nonvanadiferous uranium deposits with a high sulfide content is secondary enrichment probably important.

The degree and depth of oxidation is related to the lowering of the water table following canyon cutting in the present erosion cycle and to the different capacities of the lenticular sands and clays to retain pore water above the regional water table.

HEATS OF FORMATION OF SELECTED METAMORPHIC MINERALS IN THE SYSTEM $CaO—MgO—SiO_2—H_2O$ AND THEIR PETROLOGICAL SIGNIFICANCE

Wilford F. Weeks
Department of Geology, University of Chicago, Chicago, Ill.

The heats of formation from the oxides for tremolite ($Ca_2Mg_5Si_8O_{22}(OH)_2$), anthophyllite ($Mg_7Si_8O_{22}(OH)_2$), and rankinite ($Ca_3Si_2O_7$) and a heat of solution value for actinolite

($Ca_2(MgFe)_5Si_8O_{22}(OH)_2$) have been determined by solution calorimetry. A mixture of 20 per cent hydrochloric and 5 per cent hydrofluoric acid at 81°C. was used as the solvent. The results, corrected for the thermal effects of impurities, are tremolite $\Delta Hf_{298} = -120{,}840 \pm 1460$ cla/mole, anthophyllite $\Delta Hf_{298} = -72{,}880 \pm 1800$ cal/mole, and rankinite $\Delta Hf_{298} = -54{,}765 \pm 500$ cal/mole. These values combined with other previously determined heats of formation are used to discuss the relative dissociation temperatures of brucite, anthophyllite, and tremolite:

(1) Brucite → Periclase + H_2O

(2) Anthophyllite → 7 Enstatite + Quartz + H_2O

(3) Tremolite → 2 Diopside + 3 Enstatite + Quartz + H_2O.

The dissociation temperatures of these minerals at 1 atmosphere H_2O vapor pressure are calculated to be brucite, 290°C.; anthophyllite, 300°C.; and tremolite, 590°C. The dissociation of tremolite to diopside + anthophyllite + quartz + water is shown to be improbable because it would take place at a higher temperature than reaction (3) and it would produce anthophyllite outside of its stability field. The equilibrium distribution of calcium and magnesium among the various silicate structures is discussed by the use of the thermochemical data and is in excellent agreement with the theoretical predictions of Ramberg. The possibility of the stable existence in nature of the mineral assemblage diopside + anthophyllite and the sequence of reactions occurring during metamorphism of siliceous limestones are also discussed.

EFFECT OF HEAT ON VERMICULITE AND MIXED-LAYERED VERMICULITE-CHLORITE

E. J. Weiss and R. A. Rowland

Department of Ceramic Engineering, The University of Texas, Austin, Texas; Shell Development Company, 3737 Bellaire Boulevard, Houston, Texas

The position and intensity of the first- and second-order basal spacings of vermiculite and mixed-layered vermiculite-chlorite were measured at intervals of 5°C. to 10°C., while the samples were heated at a rate of 5°C. per minute to 900°C. These data are presented as oscillating-heating x-ray-diffraction diagrams showing the intensity change with temperature, with important spacing changes indicated, and as graphs showing the change in spacing with change in temperature.

The (001) of vermiculite remains at 14.2Å to 80°C. On losing one water layer at 80°C., the (001) shifts to 11.5Å with a one-third intensity decrease. At 215°C., the spacing shifts to 10.1Å, and the intensity decreases by about one half. Above 215°C., the spacing gradually decreases to 9.3Å at 850°C. At 900°C., the maximum disappears. The weak (002) behaves like the (001).

The intensity of an orthochlorite (001) (14.2Å) remains constant to 475°C. where it rapidly quadruples and shifts to 13.8Å, where it remains to 675°C. The maximum disappears abruptly at 725°C. The (002) (7.1Å), several times as intense as the (001), remains constant to 500°C., then rapidly disappears as the (001) intensity increases.

A vermiculite from Nottingham, Connecticut, approximately 60-40 chlorite-vermiculite mixed-layer material, combines the low-temperature intensity and spacing shifts of vermiculite and the 500°C. intensity increase of chlorite on a reduced scale.

The (001) (14.2Å) of jefferisite, Westchester County, Pennsylvania, an 80-20 mixed-layer chlorite-vermiculite, behaves like vermiculite. The (002) behaves like the (002) of chlorite.

LATE PALEOZOIC EDISODES IN CORDILLERAN GEOSYNCLINAL HISTORY

Harry E. Wheeler

University of Washington, Seattle, Wash.

Late Paleozoic Cordilleran geosynclinal history in western United States is characterized by three major regional episodes of subsidence-deposition and three of deformation-erosion. Each deformational episode has maximum hiatal value westward, becoming minimal to absent in the virtually

continuous Millard Belt succession. The "Manhattan geanticline" is accordingly discredited, and a cyclically recurrent "Cascadia" is indicated.

The earliest presently recognizable Fraser Belt episode (beginning undated) was characterized by Mississippian shale deposition, *e.g., White Pine, Milligan, Bragdon-Baird, Arlington, Calaveras* (part), *Coffee Creek-Spotted Ridge* (part), *Elkhorn Ridge?* (part), and *Sicker?* (part). Its more coarsely detrital latest Mississippian-early Pennsylvanian upper portion includes abundant chert-, argillite-, and quartzite-pebble conglomerates and graywackes (manifestations of orogenic onset), *e.g., Diamond Peak, Battle, Spotted Ridge* (part), and *Elkhorn Ridge?* (part).

The hiatus representing the succeeding deformational episode embracing the entire Pennsylvanian in the coastal States is progressively closed eastwardly into the continuously subsident Millard Belt (*lower Oquirrh*, etc.)

A unique regional blanket of "shelf" limestone denotes stable Fraser Belt deposition during latest Pennsylvanian-early Permian (*Antler Peak, McCloud, Coyote Butte, upper Sicker*, etc.).

Mid-Permian is hiatal in the Fraser Belt but present in the continuous Millard succession (*uppermost Oquirrh*, etc.).

Regionally subsident late Permian, characterized westward by volcanics and detrital sediments (*Koipato, Taylor to Robinson, Nosoni-Dekkas, Clover Creek, Seven Devils*, etc.), grades eastward into nonvolcanic *Phosphoria* equivalents.

Absence of latest Permian, together with unconformable Triassic, indicates a final Paleozoic western Cordilleran positive, while Permo-Triassic sedimentation was generally continuous in the Rocky Mountain region (*Embar-Chugwater*, etc.).

GLACIOLOGICAL STUDIES OF TWO OUTLET GLACIERS, NORTHWEST GREENLAND 1953

Sidney E. White
The Ohio State University, Columbus, Ohio

Glaciological studies of two outlet glaciers, Nordre Tvillinggletscher and Søndre Tvillinggletscher, 47 km northeast of Thule, Greenland, from July 2 to August 29, indicate two periods of maximum melting for 1953, the first in late June and early July primarily due to solar radiation, and the second in late July and early August primarily due to warm winds and warm rains. Average amount of melting off glaciers during 8 weeks of record was 77 cm (water equivalent 62 cm). Approximately 5.8 million cubic meters of water was discharged from the two glaciers during the same period. Nordre Tvillinggletscher is relatively free of crevasses, but the shorter, wider, and faster-moving Søndre Tvillinggletscher has numerous areas of crevasses 2–8 meters wide which eventually reseal by pressure and by refreezing meltwater, or melt out. Nordre Tvillinggletscher moved an estimated annual 15.7 m (also 16.7 m in 1954), and Søndre Tvillinggletscher 32.5 m (30.2 m in 1954). Nordre Tvillinggletscher, measured hourly for 24 hours, jerked with a pulsation similar to that known for other glaciers.

Examination of glacial deposits adjacent to the two glaciers reveals a sequence of moraines which indicate overall retreat of the main Greenland Ice Cap margin with successive shorter advances during the past 1000 years. Position, shape, and lithology of moraines, outwash deposits, ice-cored moraines, former lake levels, varved lake sediments, and also botanical evidence determined eight stages of advance and retreat.

BEECHER'S SUPPOSED ODONTOPLEURID PROTASPIS IS A PHACOPID

H. B. Whittington
Museum of Comp. Zoology, Harvard University, Cambridge, Mass.

In 1893 Beecher described a silicified trilobite protaspis etched from Lower Devonian limestones of New York; he named it "*Acidaspis tuberculatus* Conrad" because it had a spinose margin. Glabella

is divided into occipital ring, three longer rings about equal in size, and a still longer, wider frontal lobe. Cheek is wide, long, steep lateral slope, short fixigenal spine. Eye lobes far forward, proparian sutures outlining tiny free cheeks and confluent inside margin of narrow anterior border. Short spines along margin anterior border, free cheeks, and lateral margin fixed cheeks. Protaspides of *Dalmanitina* from the Ordovician of Europe have the same form as Beecher's specimen, particularly when allowance is made for their being flattened during preservation as moulds in shale. The European specimens usually lack free cheeks and doublure, the marginal spines thus being absent or concealed by flattening. One specimen from Bohemia, however, has the doublure and marginal spines preserved, and the hypostome. The writer concludes that Beecher's identification was incorrect, that the protaspis is of a phacopid. It shows that the "pre-antennal segment complex" of Størmer was represented on the dorsal side by tiny free cheeks, anterior border, and part of frontal glabellar lobe. It thus does not seem that the development of the "complex" is arrested in the early ontogenetic stages of phacopids, as Størmer claimed.

BOUNDARIES OF GEOLOGICAL PROVINCES

J. T. Wilson
Dept. of Physics, University of Toronto, Toronto, Ontario, Canada

Reliable age determinations from the Canadian, African, and Indian shields indicate that each shield can be divided into regions for which all the reliable ages determined for pegmatites lie within a limited range in time. The Appalachian pegmatites are all from 200 to 600 or possibly 800 million years old, the Grenville pegmatites are 800 to 1200 million years old, while the Keewatin pegmatites are about 2500 million years old. These are also the ages of the oldest veins in each of these provinces. Presumably these dates are the times of mountain building in these areas.

The boundaries between these provinces are at least in large part major fault zones. Lesser fault zones form systematic patterns especially on the sides of the boundaries underlain by the older provinces.

In the Canadian Shield six of these zones are described approximately along Bathurst Inlet, Snare River, Great Slave Lake, Nelson River, the Grenville front, and east side of Labrador trough. Their characteristics are described and compared with the inner boundaries of the Appalachian and Cordilleran systems. The question of the extent to which these major fault systems extend under the areas of covered shield will be discussed. It is suggested that the Gregory and some other rift valleys in Africa, although they are still active, form the faulted inner boundary of the Mozambique province of latest Precambrian age in eastern Africa.

PENNSYLVANIAN PLANT MICROFOSSILS OF THE CROWEBURG COAL IN OKLAHOMA

L. R. Wilson and W. S. Hoffmeister
University of Massachusetts, Amherst, Mass.; Carter Oil Co., Tulsa, Okla.

The Croweburg coal is an extensive seam in northeastern Oklahoma, Kansas, and Missouri. Coal residues from nine widely spaced outcrops in Oklahoma have been studied in detail for plant spores and leaf cuticles. A total of 48 species of spores, including one new genus and nine new species, are described from the flora. Four abundant leaf cuticle types also occur. Channel-sample histograms of these fossils show that the dominant spores at each locality are *Cirratriradites punctatus*, *Laevigatosporites minutus*, *Florinites antiquus*, and *Endosporites ornatus* respectively and that the same leaf cuticles occur in nearly similar percentages at each locality. Paleoecological succession of the vegetation which formed the Croweburg coal was investigated by comparing the spore populations in the lower, middle, and upper segments of the coal seam. The dominant spores in all levels are *Cirratriradites punctatus* and *Laevigato-sporites minutus*, but spore successional diagrams indicate that in the early stage of succession the vegetation was that of plants producing spores of *Cirratriradites* and *Triquitrites*. In the middle segment of the seam plants producing *Laevigato-sporites* and *Granulati-*

sporites reached their greatest relative abundance, and in the top segment those producing *Calamospora*, *Endosporites*, and *Florinites* attained their greatest abundance. The abundance of cuticle types remains essentially uniform throughout the seam. They represent the endemic plant of the coal swamp, and their uniform abundance suggests a somewhat stable local plant community. The variation in spore population may be interpreted as reflecting minor vegetational changes in the swamp and plant succession on adjacent upland.

URANIUM MINERALIZATION IN THE CAL URANIUM AND HOMESTAKE MINES, BIG INDIAN WASH, UTAH

George G. Witter, Jr., and Heinrich D. Holland
Department of Geology, Princeton University, Princeton, N. J.

In the Cal Uranium and Homestake mines located in Big Indian Wash, southeast of Moab, Utah, uranium mineralization occurs in the basal member of the Chinle formation. Forty thin sections of samples of ore from these mines were covered with alpha-sensitive stripping film, and the distribution of radioactive centers was studied in relation to the mineralogy of the ore and of the ore-bearing horizon.

The basal Chinle in Big Indian Wash consists of lenses of conglomerate, sandstone, siltsone, mudstone, and limestone. Calcite is present throughout the horizon and is believed to have been deposited as detrital grains. Pyrite is the most abundant sulfide. Barite, detected in some of the thin sections, replaces quartz grains and carries small, highly radioactive inclusions along cleavage planes and grain boundaries. X-ray studies indicate that the major portion of the uranium occurs in coffinite, usually as very small grains associated with carbonaceous material along boundaries of grains of nonore minerals

STRESS-STRAIN RELATIONSHIPS FOR IGNEOUS ROCKS

Vladimir E. Wolkodoff
Petrographic Laboratory, Bureau of Reclamation, Denver Federal Center, Denver, Colo.

Excellent correlations are established between texture, structure, and composition of igneous rocks and unconfined compressive strength, triaxial strength, Young's modulus of elasticity, and Poisson's ratio.

Strength and elasticity increase as quartz decreases in amount and plagioclase and/or ferromagnesian minerals become more abundant; however, the increase is attributed mainly to better interlocking and articulation of the crystals. Characteristic strength and elasticity are as follows for unaltered or slightly altered rock (length/breadth = 2):

Rock Type	Compressive Strength, psi × 10^3	Secant Modulus of Elasticity, psi × 10^6
Granites	20–35	4–7
Syenites, monzonites	35–50	7–10
Diorites, gabbros	45–60	10–13
Glassy volcanics	6–22	4–8
Andesites, basalts	25–50	8–12
Diabases	45–80	12–17

Porphyritic texture produces slightly higher strength, but the elasticity is similar to that of nonporphyritic equivalents. Type and degree of alteration, fabric discontinuities, porosity, vesicularity, fracturation, and seam fillings affect strength and elasticity in characteristic ways. Equal alteration, especially in feldspars, lowers strength and elasticity proportionately for all rock types. Under triaxial conditions rupture load increases linearly with lateral pressures up to 6000 psi, and a charac-

teristic slope is obtained for each rock type. The relationship is retained, although at lower strength values, for equivalent altered rock. Poisson's ratio remains nearly constant for unaltered rock as axial stress is increased to 5000 psi, whereas for similar but altered rock Poisson's ratio is smaller especially at low axial stress loads but generally increases as axial stress is increased.

FORMATION OF RIVER FLOOD PLAINS

M. Gordon Wolman
U. S. Geological Survey, Washington, D. C.

Frequency studies indicate that the flood plains of streams of all sizes flowing in diverse physiographic and climatic regions are just overtopped by the annual flood which has a recurrence interval of about 1 year.

Although the flood plain consists of both channel and overbank deposits, the proportion of the latter is generally very small. The uniform frequency of overbank flooding and the small amount of deposition on the flood-plain surface observed in great floods (average deposition .07 foot) support this conclusion. Although lateral migration of channels is important in controlling the elevation of the flood plain, rates of migration are extremely variable and alone cannot account for the uniformity of many flood-plain surfaces. This uniformity may be related in part to (1) the relatively high velocities (1–4 feet per second) which have been observed in overbank flows, and to (2) the fact that the highest flood discharges often carry lower concentrations of suspended sediment than do more moderate floods.

Because deposition on the flood plain does not continue indefinitely, the flood-plain surface can be transformed into a terrace surface only by some tectonic or climatic change which alters the regimen of the river causing it to entrench itself below its established bed and associated flood plain. A terrace, then, may be distinguished from a flood plain by the frequency with which each is overflowed.

TECHNIQUES AND GUIDES FOR EXPLORATION OF URANIUM-BEARING SHINARUMP CHANNELS ON THE COLORADO PLATEAU

H. B. Wood and W. David Grundy
Atomic Energy Commission, Grand Junction, Colo.

Detailed studies were made by the Commission of three areas on the Colorado Plateau in which uranium ore occurs in the upper Triassic Shinarump conglomerate: Circle Cliffs and White Canyon regions of southeastern Utah, and Monument Valley region of Utah and Arizona.

The following ore guides are suggested: (1) uranium ore is confined to the bottoms and sides of paleochannels and scours; (2) ore is most likely to occur in a poorly sorted, porous, argillaceous, arkosic sandstone and/or conglomerate interbedded with mudstone lenses and clay galls; (3) irregular channels with deep and narrow cross sections and with variations in depth of scour are favorable for the occurrence of this type of lithology; (4) the presence of carbonaceous material and some clay lenses is important for uranium precipitation or concentration; (5) an appreciable thickening of the zone of bleaching in the underlying Moenkopi; (6) the near-by presence of copper sulfides, sulfates and carbonates; iron sulfides, sulfates, and hydrous oxides; and cobalt arsenate.

In exploration for ore deposits it is recommended that the initial dip of the beds be reconstructed and that the pre-Shinarump topography be shown by contours indicating the shape and trend of the paleochannel. Then the projected trend of the channel is traced by drilling using fence and single-hole patterns. If the paleotopographic contours are extended ahead of the drilling, few holes will be wasted, and drilling will be confined to channels.

GRAVITY STUDIES OF MAJOR TECTONIC UNITS IN THE UNITED STATES

George P. Woollard
Dept. of Geology, Univ. of Wisconsin, Madison, Wis.

Results from a series of regional gravity reconnaissance traverses across the United States show that the Appalachian Mountain system is characterized by negative anomalies indicative of a deficiency in mass at depth in excess of that required for isostatic equilibrium. There is no indication of a similar relationship in the Ouachita Mountains or any continuity between these two mountain systems. The ancestral Rocky Mountains, the Arbuckle Mountains, etc., as well as the Middle Rocky Mountain ranges such as the Big Horn Mountaims and Laramie Mountains, appear as superimposed gravity highs on a widespread negative gravity area. This suggests that the Rocky Mountain area as a whole approaches isostatic equilibrium but that there are local departures in areas of structural derangement. Other structural elements of a more passive type such as the Ozark Dome and the Illinois Basin do not appear to have any marked gravity counterpart. Areas of marked regional metamorphism such as the Atlantic Piedmont are characterized by marked positive anomalies. In the Lake Superior syncline where similar positive anomaly values are found, over half the anomaly can be attributed to the high density of the extrusive rocks present. In most other areas, though, the major anomalies appear to be related to crustal structure, rather than near-surface density variations.

GRAVITY MEASUREMENTS IN THE VIRGIN ISLANDS

J. Lamar Worzel and G. Lynn Shurbet
Lamont Geological Observatory, Palisades, N. Y.

Ten new gravity stations on St. Thomas and 21 stations on St. Croix have been made with the Frost geodetic gravimeter. Thirteen new submarine gravity stations have been made with the Meinesz pendulum apparatus in this area forming a 200-km profile from 70 km north of St. Thomas to 50 km south of St. Croix. A chart is presented showing simple Bouguer anomalies on land and free-air anomalies at sea.

Three seismic-refraction stations along the line of profile are used as a guide in computing a structure section from the gravity-anomaly profile. The + 130 milligal anomaly on St. Thomas confirms that this platform is similar to that of Puerto Rico. The M discontinuity determined by gravity calculations to be at about 29 km beneath Puerto Rico, St. Thomas, and St. Croix rises to 22 km beneath the Anegada Trough and to 14 km under the Caribbean Sea south of St. Croix. Gravity contours on St. Croix outline the Tertiary sedimentary basin shown by geologic mapping. Rough estimates from the gravity data indicate that these sediments are in the form of a wedge reaching its greatest thickness of at least 1.2 km at the eastern margin of the basin near the south shore.

DIOPSIDE-ANORTHITE-WATER SYSTEM AT 5000 BARS

Hatten S. Yoder, Jr.
Geophysical Laboratory, 2801 Upton Street, N. W., Washington, D. C.

The preliminary liquidus diagram for the diopside-anorthite-water system has been determined at 5000 bars water pressure. At this water pressure diopside melts at 1282° ± 5° and anorthite at 1234° ± 5°. The projection on the anhydrous plane of a point on the four-phase boundary curve lies at 73 weight per cent anorthite and 1095°C, compared to the eutectic at 42 per cent anorthite and 1274°C for the dry system. The amount of H_2O in the liquid on the four-phase boundary curve of the hydrous system at 1095°C is about 8.8 per cent. The index of refraction of glass in this system decreased with increasing water content.

The possibility that some anorthosites can form from a liquid at temperatures thought to exist within the crust is suggested by the low temperature and feldspar-rich composition of the eutectic at high water pressure. Rhythmically interlayered pyroxenites and anorthosites may have been produced as a result of varying water pressure, temperature, or both. By varying the water pressure over a critical range a pyroxene or a basic plagioclase can crystallize alternately with both pyroxene and a basic plagioclase. Mechanisms for cyclically varying water pressure are available in a cooling magma.

ECOLOGIC HISTORY OF A TRANSGRESSING PENNSYLVANIAN SEA NEAR MECCA, INDIANA (PRELIMINARY REPORT)

Rainer Zangerl and Eugene S. Richardson, Jr.
Chicago Natural History Museum, Chicago, Ill.

A sample, 13 by 16 by 1 feet (Mecca Quarry), of sheety bituminous Liverpool black shale, immediately overlying the Middle Pennsylvanian Coal IIIA (Indiana nomenclature) has been split into thin laminae and the fossil content charted for each quarter inch of shale to determine the changing fauna and environment following this marine transgression. The sequence is as follows:

Lithology	Thickness (Inches)	Fossils	Fossil abundance	
Hard black sheety shale with interbedded layers of soft gray sheety shale	8	Predominantly vertebrates: *Listracanthus*, sharks, acanthodians, arthrodirelike fishes, paleoniscoid fishes Phyllocarid (?) crustacean, conodonts, cephalopods Rare: sponges, worms, orbiculoid brachiopods, (?) ophiuroids Marine algae, stems of land plants	Much more abundant in black than in gray levels	Greatest abundance at bottom, decreasing upward
Soft gray sheety shale	2½	Sharks, paleoniscoids, cephalopods, stems of land plants	Scarce but well-preserved remains, commonly articulated	
Hard black sheety shale	1	*Dunbarella*, cephalopods	Abundant	
Broken-shell conglomerate, black shale matrix	0–½	Cephalopods, spiriferid and productid brachiopods, gastropods, fusain	Abundant	
Coal IIIA				

Lack of sorting and arrangement of fossil debris indicates persistent still water, which is also shown by some phyllocarid tests and disarticulated fish remains, broken into countless fragments that remain in original relative positions on bedding planes.

Gray and black lithologies represent times of relatively favorable and unfavorable living conditions, respectively. In earliest stage of transgression, normal marine fauna entered the area, but living conditions later deteriorated with increase of organic muck in water, permitting survival of limited fauna only.

LATE WISCONSIN CHRONOLOGY OF THE LAKE MICHIGAN BASIN CORRELATED WITH POLLEN STUDIES

James H. Zumberge and John E. Potzger
Geology Dept., Univ. of Michigan, Ann Arbon, Mich.; Butler University, Botany Dept., Indianapolis, Ind.

Geological interpretation and radiocarbon dating of an excellent exposure in a wave-cut cliff on the shore of Lake Michigan near South Haven, Michigan, permits the establishment of the following absolute chronology of events for the Lake Michigan Basin: Two Creeks-Bowmanville low-water stage, 11,000 years ago; opening of North Bay outlet (end of Lake Algonquin), 8000 years ago; Lake Chippewa low-water stage, 5000 years ago; and beginning of the Nipissing Great Lakes, a little less than 4000 years ago.

Pollen profiles from the South Haven section and from a bog near Hartford, Michigan, on the Valparaiso ground moraine reveal the following forest succession in southwestern Michigan from Two Creeks time to the present: spruce-fir to Jack pine to white-red pine to oak to oak-hemlock-broadleaved forest to oak-pine. Radiocarbon dating indicates that the close of the spruce-fir period was 8000 years ago; the Jack pine period 7000 years ago; the white-red pine period 6000 years ago; the oak-pine period 5000 years ago; and the oak-hemlock-broadleaved forest (Xerothermic) 4000 to 3500 years ago.

The difference in time between Lake Algonquin and the Nipissing Great Lakes was 4000 years. The Xerothermic is correlated with the Nipissing Great Lakes at 4000 to 3500 years ago.

ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN BERKELEY, CALIFORNIA, APRIL 28-30, 1955

CORDILLERAN SECTION (GSA), PACIFIC COAST SECTION (PS), AND SEISMOLOGICAL SOCIETY OF AMERICA

VOLCANIC AND SEDIMENTARY STRATIGRAPHY IN THE CASCADE RANGE, EAST OF CHINOOK PASS, WASHINGTON

A. T. Abbott
Univ. of Idaho, Moscow, Idaho

An unusually extensive stratigraphic section in the central Cascades is exposed in the northern part of the Mt. Aix quadrangle, Washington. The basal formation is banded pre-Tertiary or earliest Tertiary argillite. It is overlain by Eocene Puget Group, Oligocene Keechelus Series, Miocene Fifes Peak andesite, Miocene Columbia River basalt, and late Tertiary to Recent volcanic rocks.

The Puget Group sandstone in this area east of the Cascade crest is at least 800 feet thick, indicating that the shore line of the large, brackish-water estuary that White assumed to be in the vicinity of Mt. Rainier is actually much farther east. The Keechelus Series of volcanic rocks, which attains an estimated thickness of 3500 feet, concordantly overlies or in places intertongues with the Puget Group. The Keechelus is here tentatively divided into four members.

Fifes Peak andesite, inappropriately called Upper Keechelus by early workers, overlies the Keechelus with angular unconformity. Its thickness is approximately 3000 feet. Where the western margin of the Columbia River basalt is found in this area, the basalt concordantly overlies Fifes Peak andesite.

Late Tertiary? To Quaternary? flows are probably younger than the Columbia River basalt although dating is difficult because the later flows were not observed in contact with the basalt.

The most recent volcanic unit, Tumac Mountain, is a 700-foot cone and crater of unconsolidated cinders that rests on a glacially scoured, high-elevation, basalt plateau. Because the cinder cone shows no marks of glaciation, it is assumed to be post-Wisconsin.

SIGNIFICANCE OF ABNORMAL FORAMINIFERA

Robert E. Arnal
Univ. of Southern California, Los Angeles, Calif.

Observations of many foraminiferal faunas reveal that abnormal Foraminifera are restricted to certain environments. In order to detect where abnormal individuals thrive, sediments from different types of environments from Tasmania, Mexico, Florida, and Southern California were examined.

In shallow bays with restricted entrances, abnormal specimens are rare but more abundant at bay head than at bay mouth. They are present in tide pools and in coastal lagoons with intermittent communication with the ocean. In the latter they are abundant and amount up to 5 per cent of the whole fauna. In inland brackish-water lakes (Salton Sea, Southern California) abnormal Foraminifera are also abundant. A study of their distribution in the lake shows they are absent in the center but present and in places abundant along the coast. The maximum abundance is found near estuaries or at places where there is an inflow of fresh water. Fresh water brings about changes in temperature, salinity, pH, turbidity, and chemical composition including nutrients. One and possibly all the preceding factors account for the large numbers of abnormal Foraminifera. No abnormal specimens were found in sediments from an open coast.

The occurrence of abnormal Foraminifera may be useful in studying ancient sediments. Occurrences of fossil abnormal Foraminifera (providing that they are typical shallow-water species) would indicate a brackish, more or less stagnant environment on a coastal region or (if abnormal Foraminifera are abundant) an inland body of brackish water.

FORAMINIFERAL CRITERIA FOR DISTINGUISHING BETWEEN NEAR-SHORE AND OFFSHORE BOTTOM PROMINENCES IN CLASTIC AREAS OF THE CONTINENTAL SHELF

Orville L. Bandy
Dept. of Geology, Univ. of Southern California, Los Angeles, Calif.

Research on modern assemblages of Foraminifera in the northern Gulf of Mexico reveals that most of the faunas of bottom prominences in water less than 100 feet deep are distinct from those on prominences in more than 100 feet of water. The shallower prominences are dominated by *Asterigerina carinata* d'Orbigny, *Sorites orbitolitoides* (Hofker), and occasionally by unusually large specimens of *Textularia candeiana* d'Orbigny. The cumulative percentage of these three species generally ranges between 10 and 50 per cent. Off the coast of western Florida, this shoal fauna is developed over large areas of carbonate bottom sediments, whereas on the mud and silt bottoms off Texas and Louisiana these species are restricted to prominences, perhaps because here the substratum is coarser-grained than the surrounding bottom sediment.

At depths of 100 feet to about 400 feet, bottom prominences are characterized by frequencies of a few to more than 50 per cent *Amphistegina lessonii* d'Orbigny together with minor numbers of other species which are normally characteristic of the sea bottom off western Florida. Off Florida this assemblage is found on reeflike features and prominences near the edge of the continental shelf where upwelling and mixing occur. The *Amphistegina* faunas probably depend directly or indirectly upon the nutrients provided in this manner. This would explain the occurrence of the *Amphistegina* fauna under a variety of circumstances insofar as distance from shore, depth of water, and bottom character are concerned.

NEW FIELD CLASSIFICATION OF THE QUARTZ MONZONITE AND GRANODIORITE OF THE BOULDER BATHOLITH, MONTANA

George E. Becraft
U. S. Geological Survey, Spokane, Wash.

Most of the rocks constituting the Boulder batholith in western Montana are chemically and mineralogically similar and fall within the quartz monzonite-granodiorite range. However, the rocks vary considerably in textures, and this, along with small compositional differences, provides a basis for mapping that is more satisfactory and yields much more information than mapping based mainly on compositional differences. The rocks are subdivided into coarse-grained, medium-grained, and fine-grained, and each of these is subdivided into a lighter and darker group. Some of the rocks may be further subdivided on the basis of presence of large potassium feldspar phenocrysts, presence of euhedral biotite phenocrysts, or presence of an aplitic groundmass.

Such mapping has resulted in the following tentative conclusions: (1) The bulk of the rock is probably a single pluton. (2) The variety of textures and fabrics is largely the result of mixing of fractions of the magma that had reached different degrees of crystallinity. (3) Rocks of varied texture and fabric are common near the margin of the batholith, and relatively uniform medium- to coarse-grained quartz monzonite-granodiorite is common deeper within the batholith.

ORIGIN AND PROPAGATION OF THE SEISMIC PULSE—CONTINUED

Hugo Benioff
Seismological Laboratory, 220 N. San Rafael Ave., Pasadena, Calif.

Evidence was presented in the 1954 meeting indicating that an earthquake wave source cannot be composed of a number of random pulses but must be a single simple pulse or wavelet. The observed complexity of seismograms is thus an expression of complexity of path in a nonhomogeneous earth. Under certain conditions the propagated pulse can be observed, and it has the form of the second, third, or fourth derivative of the error function. Sezawa, using the Stoke's wave equation with viscous damping, showed that in a Voigt solid the duration of the propagated pulse varies as the square root

of the time (or distance). Within experimental error, which is rather large Gutenberg has verified this propagation characteristic. The change in pulse duration without change in shape is derived from an attenuation constant which varies as the square of the frequency. This modifies the spectrum of the pulse in a frequency-selective manner to produce the pulse broadening. There is considerable doubt as to the legitimacy of the Voigt model representing any known solid, and it is here suggested that the observed wavelet expansion may be a result of processes other than strictly viscous ones assumed in Stoke's equation. One such process is scattering. On reasonable assumptions it is shown that the various Gaussian forms of the seismic impulse can be generated at the source itself and need not be generated during propagation, as assumed by Ricker for explosive sources.

SEISMIC ENERGY AND SPECTRUM AS RELATED TO THE STRAIN AND SIZE AT THE SOURCE

Hugo Benioff
Seismological Laboratory, 220 N. San Rafael Ave., Pasadena, Calif.

Assuming a conventional faulting mechanism and a Gaussian derivative wave form, the relationship between energy, period, amplitude, and acceleration in seismic waves and the size and strain of the source are discussed. Available knowledge of the faulting process is not sufficient to determine all the discussed wave characteristics. Experimental wave data can therefore supply information as to the nature of the mechanism at the source.

TRANSISTOR OPERATION OF THE VARIABLE DISCRIMINATOR SEISMOGRAPH

Hugo Benioff and Len Blayney
Seismological Laboratory, California Institute of Technology, Pasadena, Calif.

The fixed-carrier frequency-variable discriminator seismograph has been modified to permit operation of the oscillator with transistors in place of thermionic tubes.

The operating frequency of 100 kc is controlled by a quartz-crystal resonator. The transistor oscillator uses one transistor in a circuit modified from Shulz. The output of the oscillator is amplified with a one-stage transistor amplifier. Output from the amplifier is fed directly to the discriminator.

Silicon diodes are substituted for the germanium diodes in the discriminator. The rectified-discriminator output serves to drive the recording galvanometer without additional amplifiers.

The whole assembly thus operates from three small 1.4-volt batteries and runs approximately 1 year between replacements.

PALEOTECTONICS OF THE UPPER ORDOVICIAN, SILURIAN, DEVONIAN, AND LOWER MISSISSIPPIAN ROCKS OF PART OF THE GREAT BASIN

Harold J. Bissell
Brigham Young University, Provo, Utah

Regional stratigraphic studies demonstrate that well-known Upper Ordovician, Silurian, Devonian, and Lower Mississippian strata can be traced extensively in western Utah and eastern Nevada. In ascending order the formations are: Fish Haven dolomite, Laketown dolomite, Sevy dolomite, Simonson dolomite, Guilmette formation, Pilot shale, and Joana limestone. There is no necessity to apply a host of different formation names to these well-defined lithofacies. It is urged that the above formation names be carried from their type localities in all directions in western Utah and eastern Nevada.

Isopachous maps prepared from data gained in the studies indicate the following paleotectonic history beginning in Late Ordovician time and extending into Middle Mississippian time: (1) the development of a rising area in approximately the site of the Manhattan geanticline. This emerged as the geanticline proper as early as Simonson time and remained high well into Pennsylvanian time; (2) the formation of a broad north-south basin in eastern Nevada and western Utah. This persisted

until Early Mississippian time, with maximum sedimentation in eastern Nevada; (3) the development of subsidiary (and in instances parallel) basins in the Death Valley area, southern Nevada, and north-central Utah to southern Idaho; (4) the beginning of an east-west high from the Provo, Utah, area westward toward Wendover as early as Ordovician; by Early Mississippian time, it was a rather prominent structure. This feature also materially aided in nearly splitting the Utah-Nevada trough by Joana time; (5) the formation of a north- and northwest-trending high through the Milford, Utah, area and toward Wendover. This separated the Joana Basin on the west from the Madison-Gardner Basin on the east; (6) the development in Ordovician time of an eastern shore line in central Utah which persisted to the end of Devonian, and thereafter progressively subsided and allowed Mississippian seas to spread farther eastward than some of the earlier seas.

STATISTICAL CONSIDERATION OF LINEAR GEOMORPHOLOGICAL FEATURES OF GUADALCANAL

C. James Blom
1050 Fell Street, San Francisco, Calif.

More than 3400 linear geomorphological features were photogrammetrically measured in the heavily wooded terrain of part of Guadalcanal Island of the Solomon Islands in the South Pacific. The statistical distribution of directions of straight valleys, gullies, cliffs, ridges, clefts, or straight segments thereof describe three to six maxima in each of 24 90-sq.-km areas. These maxima most likely result from fabric elements, vertical planes, and horizontal linear features in the materials under the topography. As such they are valuable, in conjunction with field, hand-specimen, and microscopic observations, for solving problems of the geologic structure or, better, the Gefügekunde.

Progressive incision inland of drainage patterns and relics of two older drainage systems on the northern slopes suggest, as do the hanging valleys and escarpments of the southern coast, that the island is the land expression of an uptilted (B axis = N.75°W.) block (of igneous and metamorphic rocks) bounded on the south by faults along which vertical displacements of a few thousand meters occurred.

The data were taken in only 20 hours upon overlays of seven multiplex bridges, set up for extending ground-surveying control across the island in preparation for multiplex topographic compilation. Thus the elevation, orientation, dimensions, and location of morphological features may be obtained, in contrast to the qualitative information available from stereo-pair evaluation. A measured direction indicates strike of a fabric plane $\pm$ 2°–12°.

The author is indebted to the 21st Company (Base Photomapping) and the 30th Group (Topo Survey) of the U. S. Army Corps of Engineers for permission to publish this abstract.

GLAUCOPHANE SCHISTS AND ASSOCIATED ROCKS AT TWO CALIFORNIAN LOCALITIES

T. W. Bloxam
Dept. of Geology, Univ. of California, Berkeley, Calif.

(1). In a small area 2 miles north of Valley Ford, Sebastopol quadrangle, a marine erosion surface cut in Franciscan sandstones, including graywacke, tuffaceous sandstone, and associated quartz-jadeite metasediments, has locally been stripped of its cover of marine Merced (Pliocene) sediments.

A sharp discontinuity, probably a fault, separates unaltered Franciscan on the west from sheared quartz-jadeite rocks to the east. The schistose quartz-jadeite rocks are believed to be metamorphosed Franciscan sediments. The unaltered Franciscan sediments are folded about axes trending N. to N.-NW. The quartz-jadeite rocks have vertical E.-W. foliation.

Scattered profusely over the erosion surface are randomly oriented masses of pumpellyitized and glaucophanized chert, blocks of glaucophane schist, lawsonite rock, and eclogite. Many of these exhibit *Pholas* borings and are residual masses, unrelated to the immediately underlying basement.

(2). In 1894 F. L. Ransome described a critical section on the shores of Angel Island where glaucophane schists formed from Franciscan sandstones and cherts by contact metamorphism associated with an intrusion of "fourchite". These localities have been re-examined.

Blue amphiboles, including veins of the pure mineral, have developed extensively throughout the "fourchite" itself and in large blocks of included chert.

Franciscan sandstones, with associated conglomerates, along the shore of the island are regionally sheared, and jadeite occurs in them.

MARINE TERRACES AND THEIR DEPOSITS IN THE VICINITY OF SANTA CRUZ, CALIFORNIA

William C. Bradley
Stanford University, Calif.

The sea floor in the vicinity of Santa Cruz, California, is a modern wave-cut platform that truncates all bedrock structures. Its slightly concave surface slopes seaward at less than 1° and has 2–4 feet of relief due to differential erosion. Locally it is bare but elsewhere it is mantled by a veneer of sand, less than 3 feet thick, whose grain size decreases seaward.

Former wave-cut platforms occur in four prominent marine terraces in the same area. The two thus far studied are similar to the modern platform in all respects except for their mantling marine deposits. These deposits, commonly 5–15 feet thick, show laminated structures typical of beaches and no seaward decrease in grain size. Their mineralogy is similar to the mineralogy of modern beaches in the area, except that leaching of unstable minerals indicates that the deposits of each terrace are not the same age everywhere—they are oldest next to the old sea cliff and become progressively younger seaward.

The similarity between the present and past wave-cut platforms suggests they were formed in the same manner. But the dissimilarities between the sand veneer of the present-day platform and the marine deposits of the terraces suggest that the latter are not the original neritic deposits. It is believed that the marine deposits of the terraces are beach deposits which were prograded seaward across the wave-cut platforms during a slowly falling sea level.

FAULT DEPTH AND STRAIN ENERGY

Perry Byerly
Seismographic Stations, Univ. of California, Berkeley, Calif.

Reconsideration of Harry Fielding Reid's method of computing the depth of faulting in the 1906 California earthquake, using relations between acceleration and intensity developed since Reid's work, indicates that the fault depth was not greater than 10 km.

On the basis of triangulation by the U. S. Coast and Geodetic Survey, the strain energy stored just before the earthquake is computed as of the order of 10^{24} ergs. This is the same order as that of the energy computed by Reid's method for the work done along the fault. However, the strain-energy method gives only about half that computed by the work done.

PALEOZOIC STRATIGRAPHY OF THE MINERAL HILL REGION, NEVADA

Donald Carlisle and C. A. Nelson
Univ. of California, Los Angeles, Calif.

The Paleozoic section in the Mineral Hill region, Sulphur Springs Range, Nevada, comprises an autochthonous dominantly carbonate succession overlain, above the Roberts Mountains thrust, by a dominantly clastic allochthonous western facies. Both western and eastern facies range from Ordovician to late Devonian in age.

The eastern facies carbonate sequence, approximately 9000 feet thick, is essentially the Roberts Mountains section. The formations recognized are Eureka, Hanson Creek, Roberts Mountains, Lone Mountain, and Nevada. The Nevada formation, which here includes the Nevada and part of the Devils Gate formations of Merriam, has been divided into four members including a quartzite only poorly developed in the Roberts Mountains region.

The western facies, hitherto called Vinini formation and considered Ordovician, is now known to range from Ordovician to late Devonian. Vinini has been elevated to group status, within which the following three units have been separated: chert, black shale, platy limestone, graywacke, and quartzite, the Vinini of earlier usage; limestone conglomerate, chert, black shale, and quartzite; and chert conglomerate, clastic limestone, and quartzite. The latter two units are of limited areal distribution and may grade laterally into the chert-black shale facies of the Vinini.

Regional considerations suggest movement of the western facies about 50 miles eastward. The age of the thrusting in the Mineral Hill area is not established.

FACIES AND OIL POSSIBILITIES IN THE PHOSPHORIA AND PARK CITY FORMATIONS, EASTERN UTAH AND SOUTHWESTERN WYOMING

Thomas M. Cheney
U. S. Geological Survey, Menlo Park, Calif.

The rocks of the Park City and Phosphoria formation (Permian) change progressively from phosphorite, chert, and carbonaceous mudstone in the miogeosynclinal area to carbonate rock, sandstone, and red beds in the platform area. In southeastern Idaho and Wyoming the facies change is from west to east. In eastern Utah, however, this facies change is from north to south: the upper part of the phosphatic shale member of the Phosphoria formation grades from phosphorite in the north to phosphatic mudstone, to chert and slightly phosphatic mudstone, and to cherty carbonate rocks and sandstone of the lower part of the upper member of the Park City formation. Furthermore, the strata of the Park City formation in the area between the Provo River on the south and Mill Creek Canyon, near Salt Lake City, on the north consist predominantly of carbonate rock and sandstone that can be correlated in detail with and are approximately the same thickness as strata of the formation to the east in the Uinta Mountains; therefore, this central Wasatch mountain area was part of the platform during Permian time.

The variation in facies from north to south across southwestern Wyoming and northeastern Utah may be favorable for the accumulation of oil in stratigraphic traps, especially on the north flank of the large Uinta mountain anticline. The geologic environment seems somewhat similar to that in the Bighorn Basin in central Wyoming where oil is now being produced from Phosphoria equivalents.

GEOLOGIC CROSS SECTION OF THE WESTERN SIERRA NEVADA FOOTHILLS

Lorin D. Clark
U. S. Geological Survey, Menlo Park, Calif.

Structure and sequence of the layered rocks of the Sierra Nevada foothills between the Merced and Cosumnes rivers have been determined by detailed study of graded bedding and lithology along six major streams that cross the structure. The region is on the faulted western limb of a large syncline.

Major fault zones generally paralleling the northwest strike of the beds divide the rocks into (1) the eastern block, which includes sedimentary and volcanic rocks of the Calaveras formation, intruded by plutons of the Sierra Nevada batholith; (2) the central block, a narrow belt of Calaveras formation of Late Paleozoic age unconformably overlain by locally fossiliferous volcanic and sedimentary rocks of Late Jurassic age; (3) the western block, which consists of at least two pyroclastic units of probable Jurassic age separated by a slate and graywacke unit. Serpentine is present in the fault zones.

The section along the Cosumnes River is representative of the area studied. In this vicinity, granodiorite intruding the contorted beds of the Calaveras formation in the eastern block is truncated on the west by the Mother Lode fault. Near the west side of the central block, the Calaveras formation forms the core of a faulted anticline. From the Calaveras exposures eastward the dip is homoclinal, with the youngest beds on the east. West of the Calaveras exposures and separated from them by a

fault, the Cosumnes formation, with tops east, is repeated by faulting. The western block shows broad folds overturned to the west.

QUATERNARY VOLCANICS OF DEATH VALLEY, CALIFORNIA

Thomas Clements
Dept. of Geology, Univ. of Southern California, Los Angeles, Calif.

Basaltic volcanics have been studied in 16 localities in or adjacent to Death Valley. Five of these localities occur in the northern part of the valley and each contains two or more individual areas of volcanics; seven occur in the central portion of the valley, and in the southern part there are four.

The author believes all the volcanics studied are Pleistocene, except for those of the Ubehebe Crater area, which are considered to be Recent. Evidences of Pleistocene age are: (1) many of the volcanics overlie alluvial-fan material, and some are in turn overlain by similar material; (2) old erosional remnants of fans adjacent to volcanics are generally free from volcanic debris, whereas younger fans tend to be covered by volcanic boulders; (3) almost all the volcanics have been uplifted and tilted; (4) in many of the basalt areas craters, although eroded, are still discernible; and (5) those volcanics within the limits of Pleistocene Lake Manly have been terraced by wave action.

The evidences for considering Ubehebe Craters Recent are: (1) the relatively small amount of erosion exhibited by the cinder beds, which are unconsolidated; (2) the almost perfect preservation of the youngest crater; (3) the fact that cinders from the craters are found on but not incorporated in the lake beds of Pleistocene Lake Rogers.

CURRENT RESEARCH ON THE FRESH-SALT INTERFACES AT THE BASE OF GHYBEN-HERZBERG LENSES IN HAWAII

Doak C. Cox
Experiment Station, Hawaiian Sugar Planters Assoc., Honolulu, Hawaii

An experimental well on the island of Maui, Hawaii, is equipped with 14 tubes terminating at depths ranging from 18 to 211 feet below sea level, by which salinity, head, etc., may be measured at various levels in and beneath a thin Ghyben-Herzberg lens of fresh water floating in the basalt bedrock on sea water. The mean water-table elevation is about 2 feet above sea level, and the theoretical depth of the fresh-salt interface thus about 80 feet. The first salinity profiles obtained indicate a nearly symmetrical sigmoid curve with the sharpest change in salinity between 75 and 85 feet below sea level. The water at the bottom is pure or nearly pure sea water. Head profiles require further tidal averaging, but preliminary results suggest a curve similar but reversed, as expected.

Other simpler, mixing-zone sampling wells have been constructed or are planned on the island of Oahu for thicker Ghyben-Herzberg lenses resulting where structure restricts discharge to the sea.

Such wells, it is hoped, will indicate the nonsteady dynamic behavior of the fresh-water bodies sufficiently well to check theoretical analyses of such behavior. Values of deep-integrated permeability, necessary for the analyses, can be obtained by the measurement of tides propagated across the lenses from the ocean.

AMMONITE FROM THE CRETACEOUS NEAR CARLSBAD, CALIFORNIA

William H. Easton
Univ. of Southern California, Los Angeles, Calif.

Evidence is contradictory as to the age within the late Cretaceous of *Coralliochama*-bearing strata in California and Baja California. Durham and Kirk (1950) decided that two cephalopods they collected from Punta Banda, Baja California, indicated that the strata are "probably of Maestrichtian age". On the other hand Bandy (1952) found foraminifers in the *Coralliochama* beds near Carlsbad and near Point Loma, California, which he concluded correlate with Middle and Lower Campanian strata respectively in Europe. Popenoe (1953) assigned the beds an intermediate position when he

suggested that smooth *Pachydiscus* from these controversial strata are "very near the Campanian/Maestrichtian boundary" and that ribbed *Pachydiscus* represent "some part of the Campanian".

In 1950 William G. Hannah discovered a specimen of *Parapachydiscus* [*Pachydiscus*] *peninsularis* Anderson and Hanna, 1935, in float from the same outcrops from which Bandy's foraminifers came and from which Popenoe collected smooth "*Pachydiscus*" near Carlsbad. This species, however, is a ribbed form, the costae of which are intermediate in strength between those of *P. catarinae* and *Pachydiscus* sp. from the *Metaplacenticeras* beds near Santa Monica, California. *P. peninsularis*, according to Anderson and Hanna, resembles species from India and Germany which they place in pre-Maestrichtian rocks. Inasmuch as the ribbed *P. peninsularis* occurs with the smooth *P. catarinae* in some formations, the presence or absence of ribs is equivocal evidence of age. Moreover, Muir (1936) found *Coralliochama* in the Tampico region of northeast Mexico in both Campanian and Maestrichtian rocks, but those rocks within this extended range of *Coralliochama* which contain *Parapachydiscus* were assigned to the Campanian by Muir. There is evidence, therefore, that the range of *Parapachydiscus* is compatible with foraminiferal evidence that the *Coralliochama* beds may be partly of Campanian age.

SUBMARINE VOLCANOES AT SOUTHEASTERN END OF HAWAIIAN CHAIN

K. O. Emery
Geology Dept., University of Southern California, Los Angeles, Calif.

A brief survey of the sea floor as the southeastern end of the Hawaiian Islands Chain showed the presence of five seamounts superimposed atop the lower slopes of Hawaii, in the Hawaiian Deep, and on the Hawaiian Arch. Three of the seamounts rise 9000 to 12,000 feet above their surroundings, but their tops are still 3000 to 6000 feet below the sea surface. Although they differ in some respects from the islands of the volcanic chain, the seamounts are believed to be volcanoes, perhaps representative of the early stages of deep-sea volcanic cones.

FINITE-STRAIN THEORY AND THE EARTH'S INTERIOR

Jack F. Evernden
Dept. of Geological Sciences, Univ. of California, Berkeley, Calif.

A critical inspection of the finite-strain theory of Cauchy, Brillouin, Murnaghan, and others leads to the conclusion that the high-order coefficients are not small quantities. Any application of such theory to the highly stressed interior of the earth must retain these terms. The application of the theory in this form to the earth's interior leads to the following estimate of the zero-pressure values of the indicated parameters:

a—lower mantle, assuming homogeneity (1400–2900 km)

$$\rho_0 = 4.0 \text{ gm/cm}^3 \qquad K_0/\rho_0 = 27(\text{km/sec})^2$$

b—outer core, assuming homongeneity (2900–4500 km)

$$\rho_0 = 6.75 \text{ gm/cm}^3 \qquad K_0 = 1.00 \times 10^{12} \text{ dynes/cm}^2$$

(using mean of Bullen's two models).

These zero-pressure parameters indicate that the lower-mantle properties can be explained without recourse to phase-change hypotheses. The core data indicate excellent agreement with the expected properties of iron meteorites at approximately 3000°C.

TRIPARTITE RESULTS FOR THE KAMCHATKA EARTHQUAKE OF 4 NOVEMBER 1952

Jack F. Evernden
Dept. of Geological Sciences, Univ. of California, Berkeley, Calif.

The tripartite technique was applied to all portions of the record following initial *S*. The results of this study indicate that:

(1) The SV motion, extending from initial *S* to *G*, was a cohesive whole, not random motion, and is the result of continuous arrival of energy along paths of decreasing mantle penetration.

(2) The SV-, Rayleigh-, and Love-wave arrivals were all deflected from the great-circle path. These results contrast sharply with the results of earlier tripartite studies. The deflection is tentatively explained by a general downwarping of the equal-velocity surfaces in the mantle in the vicinity of the Aleutian tectonic welt.

DISPERSION OF LOVE WAVES CROSSING THE UNITED STATES

Maurice Ewing, Frank Press, and Jack Oliver
Lamont Geological Observatory, Palisades, N. Y.

The Fallon, Nevada, earthquake of 6 July 1954 provided an unusual opportunity for the study of continental Love waves. An excellent dispersion curve covering the range of periods 8–140 sec was obtained from the Palisades seismograms. Allowing for the effect of mantle gradient the observed dispersion fits a theoretical curve to within 0.1 km/sec for most of the period range 20–140 sec. An average crustal thickness of 35 km is indicated for the region between Nevada and New York.

The relative excitation of Love, Rayleigh, Lg waves for recent West Coast earthquakes is discussed.

FURTHER APPLICATIONS OF THE POTASSIUM-ARGON METHOD OF AGE DETERMINATION

R. E. Folinsbee, J. Lipson and J. H. Reynolds
Department of Geological Sciences, Univ. of California, Berkeley, Calif.; Department of Physics, Univ. of California, Berkeley, Calif.; Department of Physics, Univ. of California, Berkeley, Calif.

Sensitive potassium-argon age-dating apparatus at the University of California, Berkeley, capable of measuring radiogenic argon concentrations of a low order of magnitude, has been used in extending the method from potassium feldspars of old, coarse-grained sialic intrusives to potassium in other geologic environments.

The granite-series theory is being tested for a very old and a very young series of granitic intrusives. Intrusives of the Archean Yellowknife continental nucleus, Northwest Territories, Canada, ranging from hornblende-biotite diorites to muscovite granites, are being dated and correlated. Mesozoic intrusives of the North American Cordillera from California and British Columbia are to be compared.

Extrusive rocks, an Archean rhyolite flow and a Cretaceous alkali volcanic, are currently undergoing investigation. Tuffs, conglomerates, glauconites, and potassium salts are also being examined.

LOWER LIMIT OF THE GREEN-SCHIST FACIES

W. S. Fyfe
Inst. of Geophysics, Univ of California, Los Angeles, Calif.

Most petrologists consider that green schists represent the lowest grade of commonly recognized crystallized schists. There is evidence that large zones of even lower-grade metamorphic rocks may occur, and study of these rocks allows some estimate of the lower limit of the typical green schists.

Coombs (1954) described a 30,000-foot section of zeolitized rocks. The characterisitic minerals of the green schists are poorly developed, and in the base of the section minerals such as prehnite-laumontite are more important than the epidote minerals. Brothers (Personal communication, 1954) also reports the development from graywackes of quartz-albite-prehnite-chlorite-muscovite schists which may be compared with the assemblage quartz-albite-epidote-chlorite-muscovite so typical of the green schists.

Experimental studies of zeolites similar to those described by Coombs and of parts of the system CaO-Al_2O_3-SiO_2-H_2O indicate that the green schists are unlikely to develop in force below 300°C and in some cases 400°C. Consideration of temperature-pressure gradients indicates that regional metamorphism leading to the development of a large number of metamorphic zones is unlikely to be normal-load metamorphism. Local steepening of temperature gradients appears necessary.

FAULTING AND THE NEVADA EARTHQUAKES OF 1915, 1932, AND 1954

Vincent P. Gianella
University of Nevada, Reno, Nev.

Within the past 40 years central Nevada has experienced several major earthquakes and extensive faulting along a series of north-south trending depressions and the adjacent Basin Ranges. This faulting extends 160 miles north-south from 40° 35′ N. Lat. and 117° 30′ W. Long., to 38° 21′ N. Lat., and 117° 49′ W. Long.

The 1915 faulting, extending for 26 miles, was largely confined to Pleasant and Pumpernickel valleys and to the Tobin and Sonoma ranges. The December 1954 faults extend from the north end of those of 1932 to within 20 miles of those of 1915. There are probably faults of 1915 and 1954 within this gap. The faults of 1932 occupy an area 38 miles long, those of December 1954 65 miles long.

The faults formed in July and August 1954 west of the Stillwater Range, with a north-south length of 12 miles, had small vertical, and but little horizontal movement. The maximum vertical displacement in 1915 was 15 feet. Horizontal movement, though possibly present, was not apparent. In December 1954 vertical displacements of 15 feet are common, and the maximum was 21 feet. Right-lateral strike slip movement of 3 feet was measured in 1932, and 6 feet and 8 feet lateral movement was measured for the faulting of December 1954.

It remains to be determined what the absolute vertical movements have been and whether the horizontal displacements are of local or regional significance.

"FLOW" CASTS ON SANDSTONE BEDS

Charles M. Gilbert
Univ. of California, Berkeley, Calif.

In the *formazione marnoso arenacea* (Miocene) of the Tuscan Appenines, casts composed of sandstone in underlying mudstone are common and well developed at the bottoms of sandstone layers. Some can be described simply as groove casts; others which are asymmetrical lengthwise are called flute casts. They were undoubtedly formed by some sort of motion affecting the material of the beds in which they occur, motion that presumably occurred at the time of sediment deposition. Both groove and flute casts define a lineation on the base of any sandstone layer on which they occur, but the flute casts are also vectorial and indicate motion in a particular sense. The direction of motion inferred from these lineations throughout northeastern Tuscany was remarkably uniform, in general from the northwest toward the southeast approximately parallel to the regional structural trend.

Similar casts are less common and on a smaller scale in the *macigno* of Tuscany and in Cretaceous sandstones of central California. In these beds, too, the inferred movement tends to parallel regional structural trends. If the casts do reflect sediment movement at the time of deposition, they are of great paleogeographic significance.

CHANNEL WAVES IN THE EARTH'S CRUST

B. Gutenberg
Seismological Laboratory, 220 N. San Rafael Ave., Pasadena, Calif.

Three major low-velocity layers seem to exist in the earth's crust, of which two, the lithosphere channels, are found respectively in the "granitic" and "basaltic" ("gabbro") layer of the continents; a third channel extends from the Mohorovičić discontinuity downward into the asthenosphere. Several types of waves are guided by these channels, especially *Pa* and *Sa* by the asthenosphere channel, *Lg1*, *Lg2*, and *Rg* by the lithosphere channels; waves guided by low-velocity layers in sediments must be expected. Many records of the Southern California earthquake of July 21, 1952, show channel waves with periods and velocities as reported for other paths. The regular microseisms with periods of 4 to 10 sec have properties similar to those of the *Lg-Rg* group in earthquake records and are probably propagated by the same mechanism.

Most of these interpretations and conclusions are tentative; pertinent observations are scanty, and complications have thus far prevented development of adequate equations to calculate the amplitudes of waves guided by a given channel.

MAGNITUDE AND ENERGY: PROGRESS REPORT

B. Gutenberg and C. F. Richter
Seismological Laboratory, 220 N. San Rafael Ave., Pasadena, Calif.

With additional data, the magnitude-energy relation is provisionally revised as follows:

$$\log E = 9.4 + 2.14\,M - 0.054\,M^2 \tag{1}$$

A numerical equivalent for M up to 8.6 is

$$\log E = 9.1 + 1.75\,M + \log (9 - M) \tag{2}$$

(1) is based on

$$\log (A/T) = -0.76 + 0.91\,M - 0.027\,M^2 \tag{3}$$

where A and T apply to the epicenter. Equation (3) is derived empirically from readings of torsion seismometers and U. S. Coast and Geodetic Survey accelerographs. Amplitudes at the U. S. Coast and Geodetic Survey locations have been divided by an average factor of 2½ to compensate for difference in ground; previously this correction was neglected, and *log E* was overestimated by 0.8. The terms in M^2 are at least partly due to the response of the torsion seismometer as affected by increase of ground period with M. Equation (1) agrees well with estimates of earthquake energy based on work done in faulting; estimates based on surface waves of teleseisms are in good agreement for $M = 7$ and over but are distinctly too small compared with (1) for M less than 6.

STRUCTURE OF THE DARWIN HILLS AND TALC CITY HILLS, CALIFORNIA

Wayne E. Hall and E. M. MacKevett
U. S. Geological Survey, Menlo Park, Calif.

The Darwin Hills and Talc City Hills, which contain the Darwin silver-lead district and the Sierra talc mine, respectively, are in the Basin and Range province between the Inyo Mountains and Argus Range 160 miles north of Los Angeles.

The Darwin Hills consist of intercalated limestone, silty limestone, and siltstone in a partly overturned section that ranges from Devonian on the west to Permian in the east. The Coso batholith lies adjacent to the Darwin Hills on the west, and the Darwin pluton, underlying an area 4 miles long and 300 to 3700 feet wide, intrudes the Paleozoic rocks along the axis of an overturned syncline in the central part of the hills. The rocks are tightly folded and are metamorphosed to calc-hornfels

for as much as 4000 feet from the contact. Most contacts between formations are faults. The Darwin tear fault, which strikes N. 70° W. and has a displacement of 2300 feet, and a series of N. 70° E. faults are left-lateral strike-slip faults. The Davis thrust and the Ophir Peak normal fault strike N. and dip 30° to 50° W.

The Talc City Hills, 4 miles northwest of the Darwin Hills, consist of dolomite, limestone, and quartzite of Ordovician to Mississippian age, thrust over Pennsylvanian and Permian limestone. The overthrust sheet is broken into several blocks by steep faults that expose the underlying rocks and the thrust surface in many places.

Folding and faulting are related to forceful injection of the Coso batholith.

PLEISTOCENE EPOCH

Norman E. A. Hinds
Univ. of California, Los Angeles, Calif.

The Pleistocene is best regarded as an epoch of the Tertiary Period and not as the beginning of a second periodic division of the Cenozoic which has been called the Quaternary. The difficulty in finding boundaries between Pliocene and Pleistocene deposits in many places supports this. Furthermore, the glacial interval of the Permian was not made a periodic division of the Paleozoic even though the ice apparently was as extensive and its effects were as profound as those of the Pleistocene. The relation of the Pleistocene to the Pliocene is as close as was that of the Permian glacial interval to the earlier Permian.

With the culmination of the four Pleistocene glacial ages rainy or pluvial episodes developed which affected large areas of the earth. This apparently resulted from the equatorward displacement of the two belts of stormy westerlies by advancing polar front and also by the descent of the snow line in mountainous and high-plateau country. The effects of these pluvials, shown principally by courses of former streams and locations of former or greatly shrunken lakes, are most conspicuous in parts of desert areas but extend into other regions as well.

The Wisconsin Glacial Age culminated about 50,000 years ago in central North America and probably elsewhere. Succeeding this maximum, called the Iowan Subage, there were three advances—Tazewell, Cary, and Mankato—which did not recover by any means all the lost ground. The climax of these post-Iowan advances is variously dated at about 12,000 or 20,000 or more years ago.

At the height of the Iowan Subage, ice covered about 27 per cent of the land above sea level; now occupies about 10 per cent.

The term Recent as an epoch or period of the Cenozoic is without significance. Postglacial can be used for areas from which ice has disappeared since the Wisconsin climax, but does not apply to those that are still ice-blanketed. Therefore the present and immediate past must be regarded as part of the Wisconsin Glacial Age.

LOWER PALEOZOIC SEDIMENTARY FACIES TRANSITIONAL BETWEEN EASTERN AND WESTERN TYPES IN THE OSGOOD MOUNTAINS QUADRANGLE, HUMBOLDT COUNTY, NEVADA

Preston E. Hotz and Ronald Willden
U. S. Geological Survey, Menlo Park, Calif.

Cambrian and Ordovician rocks exposed in the Osgood Mountains quadrangle, Nevada, are in part carbonate rocks similar to the carbonate section of eastern Nevada and in part clastic sedimentary and volcanic rocks lithologically similar to the clastic facies of western Nevada. The sedimentary facies in the Osgood Mountains quadrange is believed to be autochthonous and to represent a transitional facies.

Although the region is structurally complex and the stratigraphic sequence is not complete at any one place, most of Cambrian time and much of Early and Middle Ordovician time are probably represented in the transitional facies. Rocks of Cambrian age, estimated to exceed 21,000 feet in thickness, are: the Osgood Mountain quartzite, which underlies Middle Cambrian rocks; the Preble

formation, composed of shale and limestone of Middle to early Late Cambrian age; a chert and limestone formation of Late Cambrian age; and sandstone, shale, and limestone of the Harmony formation, which is at least in part of Late Cambrian age. Ordovician rocks are: a chert-greenstone-limestone assemblage of Early Ordovician age and unknown thickness; and the Comus formation, approximately 3500 feet of limestone, dolomite, chert, and shale, of Early and Middle Ordovician age.

ENERGY DISSIPATED IN STRUCTURAL VIBRATIONS DURING STRONG EARTHQUAKE GROUND MOTION

George W. Housner
California Institute of Technology, Pasadena, Calif.

Analyses of structural vibration and observations of damage show that often structures are overstressed and suffer some permanent deformation during strong ground motion. The energy that must be absorbed by the structures is given by $\frac{1}{2} mc^2$ where m is the total mass and c, which is given by the earthquake spectrum, is essentially independent of the structure over a wide range of structural flexibility.

GEOLOGY OF PART OF THE MANLY PEAK QUADRANGLE, PANAMINT RANGE, CALIFORNIA

Bradford K. Johnson
Geology Dept., Univ. of California, Los Angeles, Calif.

The area discussed is in the southernmost Panamint Mountains, between Death Valley and Panamint Valley.

Precambrian gneisses are overlain by later Precambrian and Cambrian sediments including the Kingston Peak, Noonday, Johnnie, Stirling, Wood Canyon, Bonanza King, and Cornfield Springs (?) formations. These units have been widely recognized in southeastern California but were not reported previously from the southern Panamint Range. The lower part of this sequence is equivalent to the formations named by Murphy in an adjacent area to the north, the Telescope Peak quadrangle. His Surprise, Sour Dough, Middle Park, Mountain Girl, and Wildrose correlate with the Kingston Peak; his Sentinel, Radcliff, and Redlands, with the lower Johnnie and the Noonday; and his Hanaupah with the upper part of the Johnnie.

The next youngest strata above the Cambrian are carbonates of Permian age unconformably overlain by Lower (?) Triassic marine sediments and volcanics. Other rocks include Mesozoic plutonics, monolithologic breccias of Cenozoic age, and a thick section of Tertiary volcanics.

Two main periods of faulting and folding were in the Cenozoic (basin-range faulting) and the Mesozoic (folding and normal faulting within the range). The Mesozoic faults and folds can be dated because they affect rock as young as Triassic and are themselves truncated by quartz monzonite stocks of later Mesozoic age. A large fault of this age separates Permian from Precambrian and may omit as much as 18,000 feet of Paleozoic sediments present in near-by areas.

RECONNAISSANCE OF NORTHWESTERN CALIFORNIA, A PROGRESS REPORT

William P. Irwin and Donald B. Tatlock
U. S. Geological Survey, Menlo Park, Calif.

A geologic map of the northern Coast Ranges and Klamath Mountains provinces of California is being compiled from suitable published and unpublished maps, supplemented by reconnaissance mapping along roads of approximately 10,000 square miles of the hitherto unmapped areas.

The northern Coast Ranges consist predominantly of eugeosynclinal sedimentary and volcanic rocks assigned to the Franciscan group. Sparse fossil evidence indicates that at least part of the

Franciscan group is contemporaneous with formations exposed along the west side of the Sacramento Valley that range from upper Jurassic (Knoxville) to Upper Cretaceous. Eocene to Pliocene rocks occur mainly in the Cape Mendocino-Eureka area; several small northwest-trending areas of Tertiary rocks occur in the central part of the province. Mafic and serpentinized ultramafic intrusive rocks occur throughout the central part of the province, but coarse-grained calc-alkaline rocks are absent. The lithologic and topographic grain of the province indicates that the principal faulting trends northwest, parallel to the San Andreas fault.

The Klamath Mountains province is underlain chiefly by rocks older than those of the northern Coast Ranges. The principal formations include rocks of Precambrian (?), Paleozoic, Triassic, and Late Jurassic age; a few small areas of rocks of Cretaceous and Tertiary age are also present. Large intrusive bodies of calc-alkaline rocks, as well as mafic and serpentinized ultramafic rocks, occur throughout the province.

BLEACHING CLAY DEPOSITS, SANDERS-DEFIANCE PLATEAU DISTRICT, NAVAJO COUNTRY, ARIZONA

Geo. A. Kiersch and W. D. Keller
Univ. of Arizona, Tucson, Arizona; Univ. of Missouri, Columbia, Mo.

The Sanders-Defiance Plateau district of northeastern Arizona, an important source of activated bentonite, is located along the southwestern flank of the Plateau. Permian DeChelly sandstone crops out in the central portion of the uplift with the Triassic, Moenkopi, Shinarump, and Chinle formations around the flanks. The Pliocene Bidahochi formation unconformably overlies the older formations.

Laramide upwarping developed a structural shelf along the southwestern edge of the Plateau between the main uplift and a monocline to the west (after Repenning). The Plateau, and particularly the monocline, restricted distribution of the Bidahochi sediments; lower member rocks largely pinch out against the monocline, while the upper member was deposited across the shelf to the uplift. The shelf surface was channeled during deposition of the lower member. Subsequent ash falls accumulated in these traps, later to be buried by younger Bidahochi beds. Essentially all known bleaching clay deposits occur in a belt confined to the shelf area.

Alteration of vitric tuff to calcium montmorillonite is traced by field observation, microscopic examination, x-ray, and chemical analyses. The first step is combination with water. Mg has been added; and silica, Na, and K have been removed.

The channel and basin traps developed as a result of regional structures. Within a trap, smaller-scale structures further controlled the ash accumulation and alteration to bleaching clay—*i.e.*, depositional, deformational, and erosional pinchouts.

Potentialities for new deposits lie within: (1) limits of the shelf area; (2) Bidahochi sediments immediately overlying the shelf; (3) parent vitric ash accumulations of latitic composition; and (4) areas between the larger drainages.

ADSORPTION OF METAL IONS FROM SEA WATER

Konrad B. Krauskopf
Geology Dept., Stanford University, Calif.

Theoretically metal ions may be removed from sea water by at least four processes: (1) precipitation by ions normally present in sea water, (2) precipitation by sulfide ion in areas of low redox potential, (3) adsorption, (4) organic processes. For metals of the transition groups (1) is unimportant, as shown both by calculation and by experiment. Process (2) may remove some of the metals locally but can hardly be a major factor because concentrations of the metals bear no relation to solubilities of their sulfides. Adsorption is probably the major factor controlling metal-ion concentration, supplemented by organic processes for some metals.

Experiments show that adsorption on the more common adsorbents in the sea is relatively strong for Zn, Cu, Pb, and Hg; moderate for Mo, Ni, and Co; weak for Ag, V, and Cr. Comparison of these results with relative rates of removal of the metal ions from sea water shows good agreement for Zn,

Cu, Pb, Hg, Ag, and Mo. Ni, Co, V, and Cr are much more rapidly removed than can be explained by adsorption alone. Cr may be accounted for by reduction and precipitation as hydroxide. The remaining three are probably removed by organic processes; one observation supporting this guess is the abundance of these elements in analyses of marine organic matter.

Removal of the 10 metals by adsorption aided by organic processes may also be satisfactorily correlated with the occurrence of these elements in marine sedimentary rocks.

MIDDLE AND UPPER (?) ORDOVICIAN ROCKS OF THE INDEPENDENCE QUADRANGLE, CALIFORNIA

R. L. Langenheim, Jr., J. A. Barnes, K. C. Delise, W. A. Ross, and J. M. Stanton
Dept. of Paleontology, Univ. of California, Berkeley 4, Calif.

Four Middle and Upper (?) Ordovician formations are exposed east of Mazourka Canyon in the Independence quadrangle, California. The basal Mazourka formation, approximately 500 feet of limestone and shale, conformably succeeds nonfossiliferous, Early Ordovician (?) dolomite. Abundant sponges, including *Lissocoelia ramosa*, reaffirm its correlation with the uppermost, Chazyan part of the Pogonip limestone. The Mazourka formation becomes more platy and shaly northward.

The overlying Barrel Springs formation, approximately 150 feet of sandstone, shale, and limestone, is assigned to the Eureka Group. This formation was not observed and may be absent in the northern part of the quadrangle.

Approximately 200 feet of shaly limestone and dolomite interbedded with tongues of the Eureka quartzite make up the unnamed remainder of the Eureka Group. *Sowerbyella* (not *Sowerbyites*) and other abundant fossils suggest a Blackriveran-Trentonian age.

Approximately 175 feet of gray or black dolomite and flinty dolomite succeeds the uppermost quartzite and is tentatively assigned to the Upper Ordovician Ely Springs formation.

Silurian rocks (Waite, 1953) disconformably follow Ely Springs dolomite with a thin, prominent, basal flint bed.

Description of this section is considered significant because authors previous to Waite have placed the rocks above the Barrel Springs formation in the Devonian, and because this section is an added record of intercalation of shale and carbonate rocks in the western part of the Eureka quartzite. The Ordovician Correlation Chart (Twenhofel, 1954) does not recognize the Ely Springs formation and exchanges the lithologic descriptions of the Mazourka and Barrel Springs formations.

MINOR FRACTURES OF THE FAIRVIEW PEAK EARTHQUAKE SCARP, NEVADA

E. Richard Larson
Dept. of Geology, University of Nevada, Reno, Nev.

Minor fractures and ridges produced by the December 16 Dixie Valley-Fairview Peak earthquake Nevada, are indicative of earth movements which accompanied the major faulting. Fractures on the upthrown block of the fault are principally tensional cracks which parallel the main fault; those on the downthrown block tend to be more complex. Of particular interest are tensional cracks which parallel the slope of the hills and express downslope movements and stretching of the land surface. Associated with these are en-echelon sets of pressure ridges oriented transverse to these cracks. Complexes of shear fractures and pressure ridges on the down-dropped side of the major fault reflect the right-lateral movement along that fracture.

PALEOZOIC STRATIGRAPHY IN THE DARWIN QUADRANGLE, INYO COUNTY, CALIFORNIA

E. M. MacKevett and Wayne E. Hall
U. S. Geological Survey, Menlo Park, Calif.

A section of Paleozoic rocks in the Darwin quadrangle, Inyo County, California, ranges in age from Early Ordovician to Permian and has an aggregate thickness of 13,000–14,000 feet. A continu-

ous stratigraphic sequence is lacking because of faulting or separation of the outcrops of Paleozoic rocks by alluvial or volcanic terranes. Although most of the rocks are metamorphosed, they commonly retain their sedimentary characteristics.

The Paleozoic rocks are predominantly carbonates and, in general, correlate with the eastern or carbonate facies of Basin and Range deposits of Paleozoic age. The pre-Devonian rocks, except for the Eureka quartzite, are preponderantly dolomite. Devonian rocks consist of limestone, dolomite, and subordinate quartzite and shale. The post-Devonian Paleozoic rocks are mainly limestone but also include shale and conglomerate. Formation names used by J. F. McAllister in the adjacent Ubehebe Peak quadrangle and Quartz Spring area and by C. W. Merriam in the Cerro Gordo area are applicable to most of the Paleozoic rocks of the Darwin quadrangle. A new formation of Pennsylvanian(?) age is believed to be a stratigraphic equivalent of McAllister's Rest Spring shale. The paleontologic record is best represented by an abundant fusulinid fauna in the Pennsylvanian and Permian rocks and by brachiopods and corals in the lower Mississippian Tin Mountain limestone.

ELEVATION CHANGES IN CENTRAL CALIFORNIA

E. C. Marliave
Sacramento, Calif.

Changes in elevation in the San Joaquin Valley and adjacent mountain areas have in recent years posed serious problems to those engaged in planning, operating, and maintaining both major and minor engineering structures.

The principal causes of the phenomena in this area are as follows:

(1) Tectonic
   a. Slow uplift or sinking
   b. Rapid uplift or downdrop (faulting)
      May be accompanied by slumping or compaction
(2) Extraction of fluids and/or gases
(3) Compaction of surface materials because of heavy irrigation
(4) Swelling clays
(5) Removal of solubles by solution

Elevation changes by oxidation of organic material, loading, drying and shrinking and wind erosion may occur but are not considered important.

Preliminary studies are being made to determine possible means of predicting subsidence.

GEOMORPHOLOGY OF JORDAN VALLEY, UTAH

Ray E. Marsell and Daniel J. Jones
Dept. of Geology, Univ. of Utah, Salt Lake City, Utah

Jordan Valley is a horseshoe-shaped structural valley, encircled on three sides by mountains and joining on the remaining side the plain occupied by Great Salt Lake. Jordan River, which bisects the valley unequally, traverses it from south to north on its way to Great Salt Lake. Jordan Valley exhibits a complex landscape consisting of three geomorphic units: the mountain fronts, the central flat, and the intervening piedmonts. The eastern piedmont is a narrow, down-faulted bajada along the Wasatch fault zone; the western piedmont is a shallowly entrenched pediment carved on tilted late Tertiary sediments and tuffs, but thinly veneered with Pleistocene lake sediments and Recent alluvium.

A marked topographic unconformity separates the bold and rugged mountain fronts from the valley floor and intervening piedmonts, the latter having been formerly covered by the waters of at least three Pleistocene lakes. Relict land forms in the piedmont zones are of both glacial and lacustrine origin, caused by processes that have long since ceased to operate. These relict land forms include more than 50 abandoned shore lines, some strongly engraved, others faint, also numerous shoreline

embankments such as: spits, hooks, baymouth bars, and deltas. Well-preserved terminal moraines of Wisconsin age are present at the mouths of several of the canyons in the loftier portions of the Wasatch Range.

Recent stratigraphic and paleontologic studies of the Pleistocene sediments in Jordan Valley by the junior author strongly indicate that both the Bonneville and Stansbury terraces, as defined by Gilbert, are relict features of a much older Pleistocene lake and were not associated with Lake Bonneville proper.

LATE PLEISTOCENE DIVIDE OF THE CORDILLERAN ICE SHEET

W. H. Mathews
Univ. of British Columbia, Vancouver, B.C.

The flow pattern of the Cordilleran ice sheet in its last active stages is revealed by drumlinoids, glacial grooves, and surface erratics. These indicate a general outward movement from an ice divide crossing the southern interior of British Columbia from the Cariboo Mountains at Lat. 52½° N. to the Coast Mountains at Lat. 51° N., and extending northward near the eastern edge of the Coast Mountains to Lat. 54° N., thence via the Babine Range, Skeena and Cassiar Mountains, and Long. 131° W. to Lat. 64° N. Highest known traces of ice action in the ice divide region decline from almost 9000 feet above sea level in the south to about 6000 feet in the north. Many mountain ranges apparently stood above the ice sheet and constituted subsidiary centers of accumulation with local ice divides; examples are the main ranges of Vancouver Island and Queen Charlotte Islands, the northern Coast Mountains, and the St. Elias Range.

The surface slope of the ice sheet in its recessional stages, as shown by the prevailing direction of drainage of meltwater channels, was nearly everywhere away from the ice divide.

EFFECT OF FOUNDATION COMPLIANCE ON EARTHQUAKE STRESSES IN MULTISTORY BUILDINGS

R. G. Merritt and G. W. Housner
California Institute of Technology, Division of Engineering, Pasadena, Calif.

See abstract in *Bulletin of the Seismological Society of America*, vol. 44, no. 4, October 1954, page 551.

LATE PRECAMBRIAN-EARLY CAMBRIAN STRATA, WHITE-INYO MOUNTAINS, CALIFORNIA

C. A. Nelson and L. J. Perry
Univ. of California, Los Angeles, Calif.; 685½ Levering Ave., Los Angeles, Calif.

In the White-Inyo Mountains of eastern California late Precambrian to early Cambrian sediments comprise an essentially conformable section approximately 22,000 feet thick—the thickest section of this age reported from the Great Basin. These strata have been differentiated into the Roberts, Wyman, Reed, Deep Spring, and Campito formations (all unfossiliferous) and the *Olenellus*-bearing Silver Peak group.

All contacts except the Campito-Silver Peak have hitherto been described as unconformities apparently because of differences in degree of structural deformation and metamorphism or on stratigraphic grounds. Current field studies reveal that attitudes in all formations are in accord; intensity of deformation and metamorphism is not a function of increasing age; and omission of strata ascribed to erosional intervals is due to faulting and failure to recognize clastic-carbonate facies changes.

Broad areal studies indicate that the Reed dolomite rests above a regional unconformity. However, the existence of other erosional breaks, especially between the Reed, Deep Spring, and Campito formations is doubtful.

The base of the Cambrian had been drawn at the supposed unconformity beneath the Campito

sandstone, thereby making some 5000 feet of faunally barren strata Cambrian. Conformability of much of the section necessitates the abandonment of this convention. On the other hand, inhospitable environments suggested by the Campito and older rocks make preservation of any early Cambrian forms unlikely, and these strata may well be in part Cambrian. These factors indicate that the base of the Cambrian cannot yet be drawn in this section.

RESPONSE OF A CRITICALLY DAMPED MECHANICAL SEISMOMETER TO WAVELETS

John M. Nordquist
Seismological Laboratory, California Institute of Technology, Pasadena, Calif.

The seismometer equation is solved as an integral containing the acceleration of the earth. Numerical solutions are given for ground displacements of the forms

$$x(t) = e^{-1/2(t/\lambda)^2} \text{ and } x(t) = -t\, e^{-1/2(t/\lambda)^2}$$

for several ratios of seismometer period To to the wavelet parameter λ.

CRUSTAL STRUCTURE OF THE INDIAN OCEAN BASIN FROM RAYLEIGH-WAVE DISPERSION

Jack Oliver, Maurice Ewing, and Frank Press
Lamont Geological Observatory, Palisades, N. Y.

Earthquake surface waves of the Rayleigh type show that the crustal structure underlying the Indian Ocean Basin is identical to that beneath the Atlantic and Pacific oceans within the limits of accuracy of the method. The Mozambique Channel may be underlain by the continental type of crust. The average thickness of unconsolidated sediments on the Indian Ocean Basin is about 1.0 km.

REDESCRIPTION OF THE SINGLE-LAYER STRUCTURE OF THE MICAS

A. Pabst
Univ. of California, Berkeley, Calif.

It can be shown that the structure of single-layer micas described by Hendricks (1939) as "monoclinic hemihedral", space group $C_s^3 - Cm$, is very nearly holohedral. By adjustments in the x coordinates of some of the atoms not exceeding 0.005 and a new choice of origin at a center of symmetry all atomic co-ordinates can be brought into conformity with the conventional description for structures in space group $C_{2h}^3 - C2/m$. It is suggested that this description is preferable since no evidence is known requiring the lower symmetry previously assigned.

GALEITE, A NEW MINERAL FROM SEARLES LAKE, CALIFORNIA

A. Pabst, D. L. Sawyer, and George Switzer
Univ. of California, Berkeley, Calif.

Galeite, a new mineral from Searles Lake, California, is named in honor of Mr. W. A. Gale, Director of Research of the American Potash and Chemical Corporation. Analysis (wt%): NaCl 6.27, Na_2SO_4 75.39, NaF 17.43, ignition loss (at 120°C.) 0.10, total 99.19. Cations other than sodium are present only as traces. The formula may be written $Na_2SO_4 \cdot Na(F, Cl)$, as for schairerite, with the ratio Cl/F close to 1/4.

Galeite has been found only in drill cores. It occurs in small nodular aggregates of minute white crystals, embedded in clay and other salt minerals. Maximum dimension of crystals is about 1 mm. In some nodules it is associated with gaylussite and northupite. The crystals are hexagonal, barrel-

shaped, rarely tabular, but a single rhombohedron with rho 66° 25′ is the most persistent form and clearly indicates that the *c* axis is trigonal.

Numerical constants for galeite are:

a_0 12.17 ± 0.02Å, c_0 13.94 ± 0.02;
Space Group $D_{3d}^1 - P312/m$ (or $C_{3v}^2 - P31m$ or $D_3^1 - P312$)
Cell Content 15 formular units
S. G. Measured (by suspension) 2.605 ± 0.005, calculated 2.611
Uniaxial positive, $nO = 1.447 \pm 0.002$, $nE = 1.449 \pm 0.002$
$nE - nO = 0.002$ by direct measurement.

Galeite is closely related to schairerite whose cell dimensions are a_0 12.17, c_0 19.29, cell content 21 formular units in agreement with Frondel (1940). Possible space groups for schairerite are the same as for galeite. If, for crystals in these space groups, the forms are to be referred to axes corresponding to those of the lattice, rhombohedra or trigonal pyramids become second-order forms. Complete correlation of morphology with lattice was obtained for each species.

Some crystals of galeite show evidence of disorder in stacking in the *c*-axis direction and of interlayering with subordinate sheets of schairerite structure. They may be considered "polycrystals" in the sense of G. Donnay (1953).

The artificial double salt, $Na_2SO_4 \cdot NaF$, described by Foote and Schairer (1930) has been considered by Frondel (1940) and by Foshag (1931) to be "artificial schairerite", and attempts have been made to use the same axes of reference for both schairerite and this artificial material. $Na_2SO_4 \cdot NaF$ single crystals obtained from Schairer and similar single crystals grown from a melt of the same composition have the cell dimensions a_0 27.8, c_0 24.5 and possible space groups $R\bar{3}2/m$, $R3m$ or $R32$.

PRELIMINARY STUDIES OF SOME OF THE ORE DEPOSITS IN THE NORTHERN PART OF THE BOULDER BATHOLITH, MONTANA

Darrell M. Pinckney
U. S. Geological Survey, Spokane, Wash.

Two major types of veins occur in the Jefferson City quadrangle and the adjacent Clancy district in the northern part of the Boulder batholith: (1) quartz veins from which base and precious metals have been produced, and (2) veins consisting mainly of chalcedony, which occur in zones and some of which contain small deposits of silver, uranium, and gold.

Most of the chalcedony veins contain several generations of chalcedony and microcrystalline quartz and trend either E. or N. 60° E. They occur northwest of Boulder and near Clancy.

Most of the quartz veins occur west of a line connecting the two areas of chalcedony veins, in east-trending steeply dipping shear zones along which are found ore bodies containing galena, sphalerite, pyrite, arsenopyrite, chalcopyrite, and tetrahedrite associated with tourmaline, quartz, and also iron, manganese, and calcium carbonate minerals. Most of the quartz veins contain most of the ore and gangue minerals listed above, but the amounts and proportions of the minerals vary from vein to vein, from district to district, and along the strike of individual veins. Some of the veins contain uranium.

Indistinct zoning in the quartz veins is suggested by a higher content of chalcopyrite in veins east and northeast of the silver-lead deposits at Wickes and by an increase of carbonate minerals toward the ends of the Comet-Gray Eagle shear zone. Incomplete evidence indicates vertical zoning in the veins at the Comet, Gray Eagle, and Gregory mines.

CRETACEOUS OF SIMI HILLS, SOUTHERN CALIFORNIA

W. P. Popenoe
Dept. Geology, Univ. of California, Los Angeles, Calif.

Unnamed massive sandstones cropping out along Santa Susana Pass and the eastern and southern margin of the Simi Hills, Los Angeles and Ventura counties, California, were early thought to be of

Eocene age, but recently have been recognized as later Cretaceous. Faunas recently obtained from both base and top of this sandstone series permit closer delimitation of age. Beds just beneath the sandstone base contain *Metaplacenticeras* and other fossils that correlate this horizon with the Pleasants sandstone of the Santa Ana Mountains. Beds at the top of the sandstones yield giant ammonites, probably *Parapachydiscus catarinae* Anderson and Hanna, and other forms that correlate this horizon with the Ragged Valley shale of Coalinga, the Cretaceous silts and sandstones of the Carlsbad region, San Diego County, with the *Parapachydiscus* beds of Johnson's Ranch and Arroyo Santa Catarina, Baja California. Probable age of the sandstones of Simi Hills in terms of European stages is approximately middle Campanian-early Maestrichtean, and probably no Cretaceous cropping out in southern California is as young as the basal Moreno shale.

DISPERSION OF RAYLEIGH WAVES CROSSING AFRICA

Frank Press, Maurice Ewing, and Jack Oliver
Lamont Geological Observatory, Palisades, N. Y.

The Columbia University long-period vertical seismograph at Pietermaritzburg, Union of South Africa, was in a favorable position for receiving surface waves from the Algerian earthquakes of 9 and 10 September 1954. The dispersion of Rayleigh waves on these seismograms could be read with greater precision because the path is long (8000 km) and is free from crustal anomalies. Dispersion in the period range 10–70 sec was measured and agrees remarkably with that reported by Brilliant and Ewing for a path crossing the United States. Allowing for the velocity gradient in the mantle, an average crustal thickness of 35 km is indicated between Algeria and Natal.

A minimum value of group velocity of Rayleigh waves, $u = 2.95$ km/sec, $T = 17$ sec was observed for the first time.

LATERITIC SILICIFICATION OF SERPENTINE IN THE SIERRA NEVADA

Salem J. Rice and George B. Cleveland
Calif. Division of Mines, Ferry Building, San Francisco, Calif.

Resistant cappings, principally rather dense silica boxwork grading into massive, jasperlike silicified serpentine, occur on many hills and ridges underlain by serpentine in the foothills of the Sierra Nevada. In places these cappings are 100 feet or more in thickness. They have generally been called silica-carbonate rocks, a designation which suggests a hydrothermal origin similar to that of the silica-carbonate rocks with which the principal quicksilver deposits of the Coast Ranges are associated. However, detailed study of several caprock occurrences has indicated they are the result of supergene deposition, the silica presumably derived from the lateritic decomposition of serpentine subjected to intense weathering during early Tertiary time.

Criteria suggesting this origin are:

(1) The silicified zones form essentially flat-lying caps on serpentine hills and ridges.

(2) No sulfides or other minerals giving evidence of hypogene origin have been found in the silicified material.

(3) The only carbonate mineral present is white porcellaneous magnesite, which occurs sporadically as veins in the lowermost portion of the silicified zone and in the serpentine immediately below it.

(4) Garnierite, the characteristic nickel-magnesium silicate of lateritic nickel ores, occurs as cavity fillings in the silica boxwork and as veins in both the silicified serpentine and fresh serpentine immediately below it.

(5) Some evidence of the time of silicification is indicated in the vicinity of Valley Springs, Calaveras County, where silicified serpentine is overlain by rhyolitic tuffs of the Miocene Valley Springs formation.

GEOLOGIC CONSIDERATIONS OF ARTIFICIAL RECHARGE

Raymond C. Richter
California State Division of Water Resources, Sacramento, Calif.

Artificial recharge to ground water is now an important technique and will become increasingly significant in the future conservation of California's water resources.

Selection of recharge sites must be based on evaluation of surface materials for maximum percolation rates and physical characteristics of underlying sediments for most efficient utilization of storage capacity and transmissibility of aquifers.

Texture of surface soils determines initial and sustained percolation rates. Three general classes of soil are proposed in which percolation rates range from 0.1 to 6 acre feet per day per acre.

Geologic and hydrologic conditions that are determining factors in rates of percolation, storage capacity, and transmission below the soil horizon include: (1) permeability of aquifers and effect on transmission rates of ground water to areas of heavy pumpage; (2) specific yield and thickness of sediments as related to potential storage capacity; (3) structural and lithologic barriers as impediments to ground-water movement; and (4) position of ground-water levels as affecting percolation rates and storage capacity.

Majority of active recharge projects in California overlie upper portions of coarse debris cones. Less favorable active recharge sites overlie pressure aquifers in central portions of ground-water basins.

ADDITIONAL DATA ON THE AGE AND EXTENT OF THE ROBERTS MOUNTAIN THRUST FAULT, NORTH-CENTRAL NEVADA

Ralph J. Roberts and Robert E. Lehner
U. S. Geological Survey, Menlo Park, Calif.

The Roberts Mountains thrust fault is probably the most important structural element in central Nevada. The thrust separates a clastic and volcanic facies on the west from a carbonate facies on the east. The upper plate of the thrust has ridden eastward or southeastward at least 45 miles. The thrust is known from the Monitor Range, southwest of Eureka, to the Nevada-Idaho State line north of Jarbidge (about 200 miles).

The western facies that makes up the upper plate contains rocks of Cambrian to Mississippian age—mainly quartzite, shale, and chert, with some greenstone, which aggregate more than 40,000 feet. The rocks of the eastern facies, below the thrust, range from Cambrian to Mississippian; limestone is the principal rock type, with some shale and quartzite. The aggregate thickness of pre-Pennsylvanian eastern facies rocks in the Eureka district is about 23,000 feet. It is thought that the eastern and western facies were deposited in a single geosynclinal basin, the thicker clastic facies on the west, the thinner shelf sediments on the east.

The thrusting was originally considered to be Laramide, but near Carlin, Nevada, conglomerate and limestone of Pennsylvanian age rest unconformably upon rocks of both the eastern and western facies. This suggests that the thrusting began in or before Pennsylvanian time. The limestone and conglomerate are viewed as part of a widespread overlapping sequence that was deposited throughout north-central Nevada.

TILT AND ROTATION OF THE AXES OF VIBRATION DURING RAYLEIGH-WAVE MOTION

Carl Romney
Seismographic Station, Univ. of California, Berkeley, Calif.

The ground motion observed during the passage of Rayleigh waves is often not that predicted by the classical theory—*i.e.*, retrograde elliptical motion in the plane of propagation with the major

axis vertically oriented. In particular, the approximately elliptical ground-particle trajectories may have their major axes inclined at an appreciable angle from the vertical, and sometimes successive cycles have a regularly changing inclination that has been described as rotation of the axes. It is shown that this tilt and rotation results from changes of amplitude of the wave train. Assuming that the vertical and horizontal components of Rayleigh motion are represented by:

$$Z(t) = gA(t) \cos wt$$

$$H(t) = A(t) \sin wt$$

it follows that the maxima of the total ground motion occur at an angle Θ from the vertical given by:

$$\sin 2\theta = \frac{2g}{(g^2 - 1)w} \frac{1}{A(t)} \frac{dA(t)}{dt}.$$

This relation is shown to fit observations of Rayleigh waves.

STRUCTURAL SIGNIFICANCE OF GRAVITY SURVEYS NEAR RENO, NEVADA

C. H. Sandberg and George A. Thompson
U. S. Geological Survey, Menlo Park, Calif.; Stanford University, Calif.

As part of the U. S. Geological Survey studies in the Mount Rose and Virginia City quadrangles, Nevada, gravity surveys were made to investigate the concealed Cenozoic structure in the alluviated basins and to explore for significant gravity differences between basins and ranges. The gravity data have been computed as complete Bouguer anomalies, which incorporate corrections for all the accurately assessable factors affecting gravity values, including topographic irregularities but not isostatic compensation.

Gravity variations in the basins are closely related to changes in thickness of basin sediments. The gravity data indicate that the light Cenozoic sediments near Reno thin abruptly to the east, half a mile from the Virginia Range, suggesting a concealed fault with a vertical displacement of at least 1000 feet; that the sediments of the northern part of Steamboat Valley are only about 300 feet thick and thin gradually eastward but abruptly to the west near Steamboat Hills; and that the valley block has been tilted westward along the Steamboat Springs fault system, but with no pronounced displacement of the bedrock surface under the prominent fissures of the main spring terrace.

From the eastern boundary of the area surveyed, the gravity values decrease westward about 1 mgal per mile, a total of 30 mgal, to a minimum at the Carson Range of the Sierra Nevada and then increase toward the main Sierra block. There is little or no gravity expression of the Virginia Range relative to the sediment-free parts of the basins east and west of the range.

PHYSICS OF OROGENESIS IN THE LIGHT OF NEW SEISMOLOGICAL EVIDENCE

A. E. Scheidegger
Dominion Observatory, Ottawa, Canada

During the past 20 years, many studies of the displacements taking place during the occurrence of an earthquake in its focus have been published. In the present paper, the results of these studies have been collected, and their bearing upon the physics of orogenesis has been analyzed. The main features of the displacements within the Earth's mantle and crust are that (1) they are localized in almost planar zones dipping at some intermediate angle beneath recent mountain and island belts, and (2) the differential displacements are to a large extent horizontal—*i.e.*, not parallel to the dipping planar zones.

A renewed discussion of the possible rheological mechanics in the Earth's mantle and crust yields that there is seemingly no known material that could entertain the displacements as they are found in the Earth. It might therefore be necessary to postulate a new type of material not heretofore encountered in the laboratory. What is required is a material in which, during failure, the direction of the differential displacements would not coincide with the surface of rupture.

The ultimate elucidation of the process of orogenesis depends on the theoretical understanding of the mechanical behavior of the material in the Earth's mantle under the conditions prevailing there, which has not yet been achieved.

ECOLOGICAL SIGNIFICANCE OF FOSSIL TRACKS AND TRAILS

Adolf Seilacher
Dept. of Geology, Univ. of Tuebingen, Tuebingen, Germany

Ichnofossils (fossil tracks, trails, and burrows) are an expression of the ecological, rather than the morphological, features of the animals that produced them. On this basis the following five-fold classification is proposed:

Resting tracks (Cubichnia)
Crawling tracks (Repichnia)
Feeding tracks (Pascichnia)
Feeding burrows (Fodinichnia)
Dwelling burrows (Domichnia)

The ecological character of an ichnofossil assemblage can be shown by an *ichnospectrum*, a graph in which each group is represented by a column the height of which represents the number of species present. Two types of ichnospectra can be distinguished in Cambrian through Tertiary rocks, each of which is accompanied by distinctive sedimentary structures and is related to certain paleogeographic areas. They represent two different ichnofacies.

The *Pascichnofacies* is characterized by a remarkable variety of specialized (mostly meandering) feeding tracks, differentiated feeding burrows, and by the lack of resting tracks. This facies occurs in sediments of the Flysch type, often associated with graded bedding, convolute bedding, and other features thought to be formed by turbidity currents.

The *Cubichnofacies* contains typical resting tracks but no feeding tracks of the meandering type. In the marine variations of this facies, a great number of feeding burrows may also be present. The Cubichnofacies occurs in shallow-water deposits.

Ichnofossils have generally no age significance, but their study (Palichnology) may be helpful in interpreting the sedimentary environment.

REACTION RATES IN THE MgO–SiO_2 SYSTEM

Charles M. Shaw
Geology Department, Univ. of California, Bacon Hall, Berkeley, Calif.

The rate of reaction of MgO with powdered silica glass in the mole ratio 2:1 was determined in the range 800°–1300°C. The average activation energy in the range 800°–1000°C is 37.3 kcal/mole.

By using coprecipitated gels in the forsterite ratio (2:1) rapid reaction can be observed below 500°C. A hydrous phase (kerolite?) is produced below about 800°C, and clinoenstatite and forsterite above this temperature. For gels in the mole ratio 2:1 a rapid reaction sets in at 750°C to form clinoenstatite, with forsterite as an intermediate step.

DIXIE VALLEY-FAIRVIEW PEAK, NEVADA, EARTHQUAKE OF DECEMBER 16, 1954

David B. Slemmons
Dept. of Geology, Mackay School of Mines, Univ. of Nevada, Reno, Nev.

The epicenter of the December 16, 1954, earthquakes is a north-south zone about 70 miles long and 20 miles wide. The two main shocks were felt in Nevada and parts of California, Oregon, Utah, and Arizona, an area of over half a million square miles.

There are many normal faults and fissures throughout the area; some mark both sides of graben valleys that moved as units, others are within the fault-block mountains and valleys. The major faults are the Dixie Valley fault on the west side of Dixie Valley and the Fairview Peak fault zone that extends along the eastern side of Chalk Mountain, Fairview Peak, and Slate Mountain. In places, the Dixie Valley fault has more than 12 feet of throw, and the Fairview Peak fault about 20 feet of throw and 12 feet of right-lateral displacement. Most fracturing occurs in zones rather than along single faults. En echelon patterns predominate in the alluvium, but minor tensional grabens separate the alluvium from mountain bedrock.

There was no loss of life or injury and only a few tens of thousands of dollars of property damage, because of the sparse population.

The water table rose 4 feet in Dixie Valley, possibly because of compaction of alluvium, and the flow of some springs was changed.

The great magnitude of the earthquake, the large area in which it was felt, and the magnitude of fault displacements mark this as one of the great earthquakes of historic time.

LANDSLIDE AT LOOKOUT POINT DAM, OREGON

Lloyd W. Staples
University of Oregon, Eugene, Ore.

During the construction of Lookout Point Dam on the Willamette River, Oregon, a landslide near the north abutment caused slight damage, although main-line traffic of the Southern Pacific was endangered, and considerable expense was incurred by the railroad in patrolling the right of way. The landslide started in the fall of 1950, after the transfer of about 5000 cubic yards of material during the excavation of a tail tower runway. Some movement is still evident, but the lake now covers part of the area, and the railroad has been relocated.

The study of the landslide (in 1954) had to be based chiefly on records and survey data. In spite of this it was clear that the prime cause of sliding was not overloading, as had been suggested, but a combination of other factors such as excessive precipitation and deforestation.

RADIOACTIVE DEPOSITS IN CALIFORNIA

Hal G. Stephens
U. S. Geological Survey, Menlo Park, Calif.

Radioactive minerals are widely distributed in California but are most common in the southeastern and southern parts. The known deposits in California are classified into four types based on the mode of occurrence: (1) deposits in fissure veins, (2) deposits localized in fractures, bedding planes, and as disseminations in porous rock, (3) replacement deposits, and (4) occurrences as radioactive accessory minerals in pegmatite or other granitic rock. Placer deposits that may contain concentrations of radioactive minerals are not included.

Primary uranium- and thorium-bearing minerals occur in pegmatite, granitic rock, and quartz veins containing base-metal sulfides, in parts of the Sierra Nevada and the Mojave Desert. The secondary uranium minerals—autunite, torbernite, and carnotite—have been identified in many localities in the Mojave Desert region, principally in association with Tertiary volcanic or sedimentary rocks.

Autunite is the important uranium ore mineral at the Miracle mine, Kern County, where it occurs as disseminations in a northwest-trending shear zone cutting granodiorite. A 255-foot adit along the vertical shear yielded enough ore to make a carload shipment in July 1954. Notable is the lack of wall-rock alteration, other than near-surface weathering, and the absence of quartz or other vein minerals.

Radium is the source of radioactivity in at least two deposits in the State, one in Plumas County and another in Kern County.

METHOD FOR PREDICTING RELATIVE SEISMIC INTENSITY AT SPECIFIC SITES

Robert Stone
Dept. of Geology, Univ. of California, Los Angeles, Calif.

Although it has long been recognized that the intensity of earthquake vibration may vary with local geology, quantitative data have been rare. Recent studies made at Koti City, Japan, by Minikama and Sakuma indicate an intimate relationship between damage distribution, alluvium thickness, and vibration character. This suggests the possibility of devising methods for determining the relative seismic intensity of specific sites *before* an earthquake occurs. Data on period, amplitude, and duration of vibration, obtained at the site from instrumental records of artifically created disturbances, could be compared with similar data obtained at previously established standard localities.

The relative intensity of vibration at these standard localities would be established using actual earthquake records. The calibration of the standards would require tables and graphs showing the effects of different thicknesses of alluvium, the effects of differences in wave velocities within alluvium and underlying bedrock, and the effects of any other measurable parameters that may prove important.

This procedure, which allows the ground itself to "integrate" the effects of numerous and complexly interrelated factors (impossible to measure in any other way), might provide a practical method for predicting relative seismic intensity; even partial achievement of this objective would add greatly to our knowledge. Success would mean that earthquake-resistant buildings could be constructed to fit the hazards of each locality, earthquake insurance rates would be set more rationally, repair expenses would be lowered, and human lives might be saved.

GEOLOGY OF THE LOOKOUT MOUNTAIN QUADRANGLE, OREGON

C. M. Swinney and C. P. Miller
Stanford University, Stanford, Calif.

The Lookout Mountain quadrangle includes rocks of the Clarno, John Day, and Columbia River formations. The volcanic Clarno formation rests upon tuffaceous sediments of probable early Eocene or Paleocene age and contains rocks of considerable textural and compositional variation. These rocks range from basalt and quartz basalt to hornblende andesite flows interlayered with mudflows and some pyroclastic deposits. The cores of several vents of Clarno age are exposed within the quadrangle. White to pale-greenish tuffaceous clays interbedded with welded tuffs are correlated with the John Day formation and rest upon a deeply weathered zone developed on the Clarno. West of Big Summit Prairie tuffs of the John Day lap out against a highland of Clarno rocks, and the entire surface is buried by the Columbia River basalt. It is believed that Big Summit Prairie represents an "island" of John Day rocks surrounded by Columbia River basalt. Land sliding of the Columbia River basalt flows upon the tuffaceous clays of the John Day formation is extensive. Formations younger than the Columbia River basalt are not present in the quadrangle. Recent erosion has produced a relief of about 3000 feet.

DEVONIAN AND MISSISSIPPIAN STRATIGRAPHY OF THE REST SPRING AREA, CALIFORNIA

Herbert Tischler
Museum of Paleontology, Univ. of California, Berkeley, Calif.

The Rest Spring area is located in the northwestern portion of Death Valley National Monument in the Panamint Range. Devonian rocks are largely represented by the Lost Burro formation, and Mississippian rocks are represented by the Tin Mountain and Perdido formations (McAllister, 1952). The boundary between Mississippian and Devonian rocks, however, cannot be drawn at the contact between the Lost Burro and Tin Mountain formations because of the common occurrence of the disputed upper Devonian brachiopod, *Cyrtospirifer* (*Cyrtiopsis* according to Crickmay, 1952),

and several Mississippian fossils found in the lower Tin Mountain formation. These problematical Devonian-Mississippian strata contain: *Caninia corniculum*, *"Lophophyllum"* sp., *Rotiphyllum* sp., *Syringopora* sp., *Choristites glennfoxi*, *Cyrtospirifer* sp., *Platiceras* (*Platiostoma*) sp., *Straparolus* (*Euomphalus*) sp., and *Hypselocrinus* sp. cf. *H. pleias*. *Cyrtospirifer* can be correlated with similar occurrences of *Cyrtospirifer-Cyrtiopsis* in the rocks of the Percha formation of New Mexico, lower Ouray formation of Colorado, Three Forks formation of Idaho, upper Palliser formation of Alberta, and Aplington formation of Iowa.

The Tin Mountain formation above the *Cyrtospirifer* assemblage contains typical Mississippian fossils: *Caninia* sp., *Caninophyllum incrassatum*, *Koninckophyllum* sp., *Rylstonia* n. sp., *Syringopora* sp., and *Spirifer* sp. cf. *S. grimesi*. The lower Perdido formation contains a new species of *Triplophyllites s.s.* which is characterized by its large size and has wide occurrence in the Mississippian rocks throughout the Great Basin.

EARTHQUAKES OFF THE NORTH PACIFIC COAST OF THE UNITED STATES

Don Tocher
Seismographic Station, Univ. of California, Berkeley, Calif.

Epicenters of most of the larger earthquakes occurring off the coast of Northern California and Oregon lie in two zones. One zone includes the submarine Gorda Escarpment which extends nearly due west from Punta Gorda. The other zone extends northwestward from the region of Cape Mendocino, indicating a linear extension of the San Andreas Rift Zone as far as Lat. 44° or 45° N.

FALLON, NEVADA, EARTHQUAKES OF JULY AND AUGUST 1954

Don Tocher
Seismographic Stations, Univ. of California, Berkeley, Calif.

Strong earthquakes occurred in west-central Nevada at 0413 P.D.T., July 6, 1954, and at 2251 P.D.T., August 23, 1954. Both earthquakes were apparently caused by movement on a fault at the eastern edge of Rainbow Mountain, about 15 miles east of Fallon. The surface breakage zone extended about 25 miles between a point near U. S. Highway 50 and the southern edge of the Carson Sink. Average strike of the breakage was N. 15° E. On July 6, normal faulting occurred on the southern 12 miles of this zone, with a maximum relative movement of 12 inches. On August 23 normal faulting occurred on the northern 20 miles of the zone, with a maximum relative movement of 30 inches. In both cases, the west side moved up relative to the east side.

AREAL GEOLOGY OF THE COYOTE DAM SITE, MENDOCINO COUNTY, CALIFORNIA*

Ray C. Treasher
520 Redwood Avenue, Corte Madera, Calif.

The U. S. Army, Corps of Engineers, San Francisco District is investigating the Coyote dam site on the East Fork of the Russian River about 5 miles north of Ukiah, California. The southeasterly flowing Russian and the southerly flowing East Fork eroded a wide valley to a temporary base level in Franciscan formation bedrock, and the valley filled with 1000 feet of alluvial materials derived from the Franciscan formation and was partially re-excavated. Remnant ridges of this old alluvium between the Redwood and Coyote valleys and south of Coyote valley form the abutments of the proposed dam. Subsequent erosion produced a series of terraces on the valley walls.

The old alluvium is characteristically blue below the water table and brown above it, is a moderately indurated and lenticularly bedded series of clayey, sandy gravels with subordinate amounts

* Presented with the permission of the District Engineer.

of clayey sands and sandy clays, and contains concretionary masses up to 18 inches in diameter. Terrace deposits consist principally of brown materials reworked from the underlying and adjacent old alluvium. Landslides are prominent on the east and south sides of the reservoir.

Northwest-trending faults are prominent, and a noteworthy feature is the many northwesterly flowing tributaries joining the southeasterly flowing Russian River. At least one post-alluvium fault has been identified. The dip of the alluvium averages 7° NW. Carbon dioxide ? and hydrogen sulfide were noted in some subsurface openings and at several places throughout the area.

NEW CONCEPT OF THE RHODODENDRON FORMATION OF HODGE

Donald E. Trimble
U. S. Geological Survey, Denver Federal Center, Denver, Colo.

An age of late Pliocene or early Pleistocene and the name Rhododendron formation were assigned by E. T. Hodge in 1933 to an assemblage of tuff breccias and lava flows that crop out between Mount Hood and Portland, Oregon. The formation now is known to overlie the middle Miocene Mollala formation of Harper and to underlie the Troutdale formation of Hodge, originally designated as Pleistocene but referred to lower Pliocene by Chaney in 1944.

In a northeast-trending outcrop belt about 5 miles wide and 25 to 30 miles long southeast of Portland, the formation ranges from about 100 to about 500 feet thick and consists predominantly of hypersthene andesite tuff breccias. At one locality, laterite developed on the tuff breccia is overlain by basal siltstone of the Troutdale formation of Hodge; the laterite is 8 to 10 feet thick and grades downward into more than 50 feet of weathered tuff breccia. This weathering of pre-Troutdale age suggests that the Rhododendron formation of Hodge is no younger than upper Miocene.

The wide lateral extent of the pyroclastic portion of the formation, an abundance of noncarbonized wood in the tuff breccia, and the absence of sorting and stratification point toward a volcanic mudflow origin of the tuff breccias. It is suggested that the mudflow originated at many volcanic vents on the west flank of the Cascade Range and merged westward into one vast, composite mudflow deposit of more than 25 miles lateral extent.

GEOLOGY OF A PART OF THE SHADOW MOUNTAINS, WEST-CENTRAL MOJAVE DESERT, CALIFORNIA

Bennie W. Troxel
Calif. Division of Mines, State Building, Los Angeles, Calif.

The Shadow Mountains are underlain by a series of late Paleozoic (?) marine metasedimentary rocks preserved as pendants in probably late Jurassic to early Cretaceous intrusive rocks. The metasedimentary series consists of unfossiliferous carbonate rocks, quartz-muscovite hornfels, platy lime-silicate hornfels, biotite schist, chert, and quartzite. These rocks resemble strata of the Oro Grande (Carboniferous) series exposed in near-by areas to the east. Metamorphism is principally dynamothermal, but in addition some rocks have been subjected to contact metamorphism. Most of the intrusive rocks are biotite-quartz monzonite and hornblende diorite. Quartz monzonite underlies most of the area and appears to be intruded by arcuate bodies of hornblende diorite up to 900 feet thick. The arcuate bodies form a discontinuous circle, possibly a ring dike, about 2 miles in diameter. Alternations of hornblende and plagioclase form layers parallel to the walls of some of the arcuate bodies and dip between vertical and 70° toward the center of the circle. Granite aplite and pegmatite in dikes and sills up to 10 feet thick are common.

A west-plunging isoclinal anticline overturned to the north is the principal structural feature of the Paleozoic rocks. Lineation in strata along the flanks of the fold plunges about 30° S. The fold probably developed in early Mesozoic time. Movement on northwest-trending faults can be resolved to vertical or horizontal components of not more than a few hundred feet.

PACIFIC COAST PLEISTOCENE MOLLUSCAN DISTRIBUTION RELATED TO MARINE CLIMATES

James W. Valentine
Univ. of California, Los Angeles, Calif.

Many west North American marine mollusks have changed their geographic or bathymetric ranges since the Pleistocene. These changes are explained by assuming that contrasts in shallow-water temperatures were greater at certain times during the Pleistocene than at present; there was a contemporaneous distribution of water which was both colder and warmer than is now normal along the west coast. As a result, forms now rather widely separated geographically or bathymetrically were able to live in close proximity and hence enter the fossil record together.

The distribution of water temperature that might be expected during glacial ages under Simpson's hypothesis illustrates this thesis. Cold waters in currents from ice-bound northern regions surfaced inshore as upwellings, while the temperature of shallow water unaffected by upwelling was raised as solar radiation increased. The ecologic composition of shallow-water Pleistocene molluscan assemblages would therefore vary in a predictable manner through the successive glacial and interglacial ages. Conditions invoked by glacial hypotheses other than Simpson's would result in similar faunal changes during the Pleistocene, though not to the same degree at the same times.

EXPERIMENTAL EVIDENCE RELATING TO SYMMETRY OF FABRIC, AND ITS BEARING ON THE PROBLEM OF LINEATION IN TECTONITES

Francis J. Turner
Univ. of California, Department of Geology, Bacon Hall, Berkeley, Calif.

The current controversy regarding kinematic interpretation of lineation in schists hinges on the significance of symmetry in tectonite fabrics. Sander's interpretation of such fabrics is based on an assumption that symmetry of fabric reflects symmetry of internal movements accompanying deformation. Some recent writers, in identifying lineation (= symmetry axis) of certain monoclinic fabrics as the principal direction of movements concerned in the evolution of those fabrics, have neglected or rejected Sander's postulate regarding symmetry. This course seems unjustified for two reasons: (1) Those who identify regional lineation with movement direction have done so for Precambrian or Paleozoic rocks whose metamorphic and deformational history is still ambiguous and highly complex; the "direction of movement" in such rocks has not been satisfactorily estabilshed independently of fabric evidence. (2) The "symmetry rule", since it was first proposed by the Innsbruck school, has become strengthened by evidence from studies on fabrics of experimentally deformed metallic aggregates and ceramic bodies. Additional support now comes from fabrics of experimentally deformed marble. In deformed marble cylinders, symmetry of fabric is shown to be identical with symmetry of movement as inferred from measurable strain. The pattern of strain is determined by the orientation of the cylinder (a mechanically anistropic aggregate of grains) in relation to applied force. Even in highly deformed material (*e.g.*, where elongation = 100 per cent) the influence of the original anisotropy on symmetry of experimentally induced movement and strain is obvious in the final fabric.

DERMATEMIDID TURTLE FROM THE ROSLYN FORMATION OF WASHINGTON

Harry E. Wheeler
Univ. of Washington, Seattle, Wash.

Two previously unreported turtle carapaces represent additions to the known vertebrate fauna of the Roslyn formation of the upper Yakima River area in the Washington Cascade Mountains. The better preserved of the two specimens is assigned to the genus *Baptemys* and appears to be closely related to *B. fluviatalis* Hay 1908 of uncertain locality, but reportedly from Colorado and presumably from the Bridger formation. Other known occurrences of *Baptemys* are in the Bridger and Wind River formations of Wyoming.

On inconclusive paleobotanical evidence, a fossil fish, and stratigraphic relations, the Roslyn formation generally has been regarded as Eocene. In terms of the Rocky Mountain vertebrate succession and the probable occurrence of *Baptemys fluviatalis* in the Bridger, this discovery appears to agree with Hesse (1936) who regarded the Roslyn fish as suggesting a middle Eocene age. It offers additional evidence in support of Weaver's (1937) estimate that the Roslyn formation belongs to the middle and/or upper Eocene, and tends to corroborate his suggestion that the underlying Teanaway basalts, together with the Metchosen lavas to the west, may represent a single basic volcanic episode. In addition, this fossil further supports the implication by G. O. Smith (1904) and Smith and Calkins (1906) that the Roslyn beds predate the Keechelus volcanics and sediments which are now known to be at least in part Oligocene (Grant, 1941).

SULPHUR BANK, CALIFORNIA, A HOT-SPRING QUICKSILVER DEPOSIT

Donald E. White
U. S. Geological Survey, Menlo Park, Calif.

Sulphur Bank, the most productive deposit that is clearly related to hot springs, has yielded 126,000 flasks of quicksilver. The ore is late Quaternary and is almost entirely restricted to rocks below the recently prevailing water table. Rock alteration and mineralogy of the veins are also related to the water table. The upper part of a Quaternary andesite flow was above the water table and was extensively leached by sulfuric acid formed by oxidation of H_2S; native sulfur without cinnabar was abundant near the surface. Stibnite is being deposited, but evidence for quicksilver is equivocal.

Waters at depth appear to be near-neutral but become acid near the surface. The present rate of discharge is about 40 gpm (calculating all discharge to chloride content of 900 ppm). Quicksilver was transported in water rather than a vapor phase; colloidal transport in near-neutral solution is suspected. The average concentration of quicksilver was between 10 and 0.1 ppm, assuming an interval of deposition between 10,000 and 100,000 years and a rate of discharge between 40 and 400 gpm.

Present temperatures are relatively low compared to typical volcanic hot springs. The distribution of sulfur, quicksilver, and silica minerals, moreover, indicates that temperatures of deposition were similar to present temperatures. In spite of association with Quaternary volcanism, the water and gases now being discharged have characteristics that favor a connate origin. Is the quicksilver also derived from sedimentary rocks?

GRANITIC XENOLITHS IN DIABASE AND ASSOCIATED HIGH- AND LOW-TEMPERATURE FELDSPARS

John F. White
Dept. of Geological Sciences, Univ. of California, Berkeley, Calif.

Xenoliths, originally granite and gneiss, occur in the diabase of central Arizona about 70 miles north of Tucson. Relict aggregates of quartz and newly formed granophyric intergrowths and perthites are characteristic of the xenoliths. These are attributed to production of a granitic magma by partial fusion of the xenoliths. Transfer of material from the diabase to the newly formed granitic magma is shown in outer portions of the xenoliths.

High- and low-temperature feldspars exist together in the xenoliths and are distinguished on the basis of habit and optics. Both high- and low-albitic plagioclases occur in the same thin section and are associated respectively with high and low types of potash feldspar. The high-temperature albitic plagioclase is An_{18}–An_{21}, 2V(−) 65–75. The low-temperature plagioclase is An_3, 2V(+) 84.

High-temperature feldspars in the xenoliths are tabular, idiomorphic, and show strong zoning characteristic of volcanic rocks; the low-temperature feldspars are hypidiomorphic granular and resemble feldspars of plutonic rocks. The "volcanic" types are attributed to crystallization from the newly formed melt, the "plutonic" types to recrystallization of some of the newly formed "volcanic" material.

TRI-METAL PLACER IN NORTH-CENTRAL NEVADA

Ronald Willden and Preston E. Hotz
U. S. Geological Survey, Menlo Park, Calif.

Gold, scheelite, and cinnabar in amounts that might be profitably extracted are found in a placer deposit in the Dutch Flat Mining district in north-central Nevada. These materials are the products of at least two and possibly three stages of metallogenic activity recorded in the district. The gold and perhaps most of the scheelite were derived from quartz veins that cut a small granodiorite stock and lower Paleozoic sedimentary rocks. Part of the scheelite may have been derived from contact-metamorphic deposits associated with the granodiorite stock. The cinnabar came from a shear zone that is later than the quartz veins. The proximity of the placer to the source of the minerals is the factor that made a significant concentration of these minerals possible. Incomplete sampling of the placer indicates an average value of $1.50 per cubic yard in combined gold, tungsten, and mercury based on the price of these metals in August 1954.

RAINBOW MOUNTAIN BRECCIAS, AMARGOSA VALLEY, CALIFORNIA

Lauren A. Wright
Calif. Division of Mines, State Building, Los Angeles, Calif.

The Rainbow Mountain breccias compose numerous tongues and lenses interlayered and interfingered with fanglomerate and siltstone of the Pliocene-Pleistocene (?) China Ranch beds, and which contain clasts of Precambrian and Cambrian sedimentary rocks, Precambrian diabase, Mesozoic (?) granitic rocks, and Tertiary volcanic rocks.

Most of the breccia masses are monolithologic; some are composite and contain individual monolithologic lenses. They range in maximum exposed dimension from several feet to as much as 1¼ miles. Some are 1000 feet or more thick. Both the masses and the planar features within them generally parallel the bedding in the bordering China Ranch beds.

The beds rest depositionally upon shattered bedrock comprising the same lithologic types as those that form the breccias. During deposition of the lower part of the China Ranch beds, this bedrock apparently was exposed along active faults, and most of the breccia bodies represent sedimentary accumulations of material derived from steep scarps. This interpretation is compatible with the recent views of L. F. Noble who once believed the breccias to be tectonic and who correlates them with the Jubilee phase of the Amargosa chaos.

The Amargosa thrust, which once was believed to extend eastward through the Rainbow Mountain area, appears to be less widespread and probably should not be projected to include thrust features along the east side of the Amargosa Valley.

ABSTRACTS OF PAPERS SUBMITTED FOR MEETING IN LARAMIE, WYOMING, MAY 6–7, 1955

ROCKY MOUNTAIN SECTION (GSA)

GEOLOGY OF A PART OF THE SOUTH FLANK OF THE SEMINOE MOUNTAINS, CARBON COUNTY, WYOMING

Howard G. Allspach

Dept. of Geology, Univ. of Wyoming, Laramie, Wyo.

The area includes approximately 60 square miles on the south flank of Seminoe Mountains eastward from Seminoe Reservoir. The Seminoe Mountains compose the central part of the south flank of the Sweetwater Arch. All geologic systems except Ordovician, Silurian, and Devonian are represented.

The Seminoe Mountains form a large east-trending asymmetric anticline with a Precambrian core. The north flank of the fold is downfaulted bringing middle Tertiary beds in contact with the Precambrian. The south flank consists of Paleozoic and Mesozoic sediments dipping southward into the Hanna Basin. The Paleozoic sequence forms flatirons and hogbacks, whereas the Mesozoic sequence is exposed in east-trending strike valleys and ridges.

Incompetent Mesozoic rocks show small folded and faulted structures not common in the adjacent competent Paleozoic rocks. The fold axes plunge eastward parallel to high-angle faults. In the northwest part of the area high-angle faulting predominates; low-angle thrust faulting is common to the west. The trend of the folded structure suggests that oblique slip on the fault planes is the result of compression from the west. Most high-angle faults extend into Precambrian rocks. Overturned beds in the southeast part of the area result from low-angle thrust faulting in the Shirley Mountains to the northeast.

Stratigraphic evidence in the Hanna Basin suggests that the major deformation in the area commenced in late Cretaceous and continued through late Eocene time. Normal faulting has tilted Miocene sediments which indicates that tensional forces were active later than middle Tertiary.

GREENHORN FORMATION OF WESTERN SOUTH DAKOTA

Richard J. Bagan

South Dakota School of Mines and Technology, Rapid City, S. D.

The Greenhorn formation (Upper Cretaceous) is exposed on all flanks of the Black Hills. Facies changes occur within the Greenhorn, and four units of varying thickness can be distinguished. The upper limestone member is topographically expressed in a series of buttes and cuestas around the periphery of the uplift. Below the upper limestone is a unit of calcareous shale underlain by a calcareous mudstone unit. The lowest unit is a calcareous shale containing a series of thin, lenticular, fossiliferous limestones which conformably overlie the Belle Fourche member of the Graneros shale. The shale and mudstone units are included in the Greenhorn on the basis of lithologic and faunal similarities.

The formation is a mappable unit and can be followed in well records. It is thickest north of the Black Hills and thins southeastward.

W. A. Cobban (1951) included the lower shale units in the Greenhorn in areas northwest of the Black Hills. This report accepts Cobban's formational boundaries and increases the area to include the southern Black Hills.

GEOLOGY OF THE SOUTH HAHNS PEAK DISTRICT, ROUTT COUNTY, COLORADO

William W. Barnwell

Univ. of Wyoming, Laramie, Wyo.

The south Hahns Peak district (T. 10 N., Rs. 85 and 86 W., Routt County, Colorado) was highland during Pennsylvanian and Permian time; 2600 feet of Mesozoic and 1200 feet of Cenozoic rock are

present. Stratigraphic formations include: Chugwater, 600–800 feet; Jelm, 230 feet; Entrada, 50–60 feet; Curtis, 110 feet; Morrison, 265 feet; Cloverly, 100 feet; Mancos shale, 1000 feet; Miocene (?) conglomerate, 0–40 feet; and Browns Park, 1200 feet thick.

Laramide trends are en echelon north-trending overturned folds and accompanying westward thrust faults, major northeast tear faults, and northwest normal faults. A transverse northeast-trending shear zone may be related to the axial flexure of the Park-Sierra Madre uplift from north to northwest at the latitude of Hahns Peak. A cross-faulted thrust zone, the Farwell zone, is 10 miles long and extends south from the eastern part of the mapped area to the Elk River.

The igneous intrusions in the district are part of the Elkhead volcanic region and may be of North Park (Clarendonian) age. The igneous rock in the district is rhyolite porphyry. Hahns Peak is a stock and was injected into a Laramide syncline, the Hahns Peak syncline. The intrusion of Grouse Mountain was controlled by Laramide structure. Most intrusions in the district are discordant to sedimentary rocks. Mafic dikes trend N. 60° W.

GEOLOGY OF THE TABERNACLE BUTTE AREA, SUBLETTE COUNTY, WYOMING

Jack E. Berman

Dept. of Geology, Univ. of Wyoming, Laramie, Wyo.

The area is located near the southwest flank of the Wind River Mountains, about 25 miles north of Farson, Wyoming, within Ts. 28 and 29 N., Rs. 104, 105, and 106 W.

Only Tertiary sedimentary rocks are exposed. The section consists of Eocene strata, except for an uppermost conglomerate unit which is probably post-Eocene, but whose exact age is not determined. The Eocene rocks are, in ascending order, the Knight formation which comprises beds of red and green mottled mudstone; the green and buff sandy and shaly Morrow Creek member of the Green River formation; and the white to gray-white tuffaceous Bridger formation. The conglomerate unit is unnamed. It is a massive boulder conglomerate.

The principal structural feature is a high-angle normal fault zone which trends N. 60° W. across the area as a series of connected, subparallel faults. Displacement along the fault zone ranges from 250 to 300 feet. The faults cut middle Miocene rocks. The fault zone is thought to be a westward continuation of the Continental fault zone which is developed farther east. It may possibly extend northwestward to the southeastern end of the Pinedale anticline. The Continental fault zone is thought to be about 60 miles long.

PHOSPHORIA BRYOZOA FROM WYOMING

Oliver D. Blake

Montana School of Mines, Butte, Mont.

The Phosphoria formation in Wyoming contains a prolific bryozoan fauna on outcrops around the margin of the Wind River Basin. This fauna is characterized by large ramose forms of Trepostomata, the most abundant and distinctive of which is a large heavily monticuled *Dyscritella*. Several species of Cryptostoma also occur. This fauna is similar to previously described Permian assemblages from other parts of the world except that this Phosphoria fauna is almost lacking in representatives of Cyclostomata, the "fistuliporid" type with interzooecial vesicular tissue. Bryozoa occur in different beds through most of the Phosphoria in this area. Throughout their vertical range no distinct faunal break is discernible.

GOULD URANIUM MINE OF THE SOUTHERN BLACK HILLS, SOUTH DAKOTA

James H. Bright

U. S. Atomic Energy Commission, Box 611, Hot Springs, S. D.

The Gould uranium mine is located approximately 8 miles northeast of Edgemont, Fall River County, South Dakota. The area is part of an extensive structural terrace immediately west of the north-south trending Chilson anticline. Stratigraphically, the deposit is in the lower Cretaceous Fall River sandstone, approximately 75 feet above the Fuson shale.

The ore body underlies an irregular contact between an impermeable silt-boulder conglomerate

and a medium- to coarse-grained sandstone. The conglomerate seals the top of the ore body. A relationship appears to exist between the tenor of the ore and a low or swale in the overlying conglomerate contact. Jointing and erratic cementation control the ore locally.

Carnotite-type minerals characterize the massive, flat-lying sedimentary ore deposit. In many places red-brown iron-oxide staining, associated with the ore as parallel banding and as massive cementation, masks the yellow color of the uranium minerals. Carbonaceous material in the ore body is not discernible megascopically.

The original discovery was made by wildcat wagon drilling near an area of low-grade surface ore in another horizon. The exploration and development program by the owners is continuously expanding the knowledge of the ore body. Present studies indicate that additional large deposits, similar to the Gould, may occur in the district.

DRUMLINS IN NORTH DAKOTA

Roger B. Colton and R. W. Lemke

U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Drumlins have been noted in North Dakota in the following areas: the Rugby-Orrin-Fillmore area in Pierce County, the Warwick-Tolna area in southeastern Eddy and southwestern Nelson counties, the Braddock area in Emmons County, the Courtenay area in Stutsman County, the Leal area, and the Valley City area in Barnes County. The Voltaire-Karlsruhe-Balfour area in McHenry and Pierce counties was described in 1954 by Lemke in a paper on the origin of linear glacial ridges in north-central North Dakota.

Nearly all the drumlins are very long in comparison to their widths; their length ranges from half a mile to 7 miles, their width from 100 to 300 feet, and their height from 3 to 25 feet. They average about a mile in length, 150 feet in width, and 10 feet in height. Shallow linear grooves in the surrounding ground-moraine plain commonly parallel the long axes of the drumlins.

The long axes of the drumlins are oriented as follows: in the Rugby-Orrin-Fillmore area a range from S. 55° E. near Orrin to S. 70° E. near Rugby; in the Voltaire-Karlsruhe-Balfour area S. 40° E.; in the Warwick-Tolna area a range from S. 22° W. in the eastern part to S. 55° W. in the western part; in the Braddock area S. 30° W.; in the Courtenay area S. 70° W.; in the Leal area S. 55° W.; and in the Valley City area a range from S. 50° W. in the northern part to S. 65° W. in the southern part.

Commonly associated with the drumlins and transverse to their long axes closely spaced lobate-recessional or "washboard" moraines mark successive positions of the receding ice front.

OCCURRENCE OF PITCHBLENDE AT THE WOOD MINE, CENTRAL CITY DISTRICT, GILPIN COUNTY, COLORADO

Avery A. Drake, Jr.

U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Much of the uranium production from the Central City district, Gilpin County, Colorado, has come from a precious metal- and pitchblende-producing vein at the Wood mine. This vein is along an easterly trending fault of small displacement that cuts Precambrian quartz monzonite gneiss, biotite-quartz-plagioclase gneiss, amphibolite, and granite pegmatite and Tertiary quartz bostonite dikes.

The vein consists chiefly of quartz; pyrite is the chief metallic mineral, and chalcopyrite is next in abundance. Sphalerite, galena, tetrahedrite-tennantite, and pitchblende are local constituents.

The veins in the Central City district are in zones; quartz-pyrite veins are near the central part of the district, and galena-sphalerite veins are on the periphery. The Wood vein is in the transition area between these zones.

Hard lustrous pitchblende in discontinuous streaks, lenses, and "kidneys" occurs on the footwall of the Wood vein within a gold ore shoot that rakes steeply west.

The pitchblende is a local constituent of the quartz-pyrite ores and probably owes its origin to residual solutions from quartz bostonite magma. Distribution of trace quantities of zirconium and molybdenum shows a direct correlation to the abundance of uranium.

MICROFOSSILS OF THE CURTIS FORMATION (JURASSIC)

Don. L. Eicher

University of Colorado, Boulder, Colo.

The Curtis formation of the eastern part of the Uinta Mountains consists of 100–190 feet of dark shales, fine-grained sandstones, and thin, fragmental and oölitic limestones, all of which contain glauconite. Its correlation with the Swift formation of Montana, eastern Wyoming, and western South Dakota and with the Stump formation of western Wyoming and eastern Idaho is widely accepted. Curtis microfossils substantiate correlation with the Swift and provide possibilities for much more detailed correlations.

The Curtis contains distinctive Ostracoda and Foraminifera very similar to the assemblage in the Swift formation. The following genera have been identified. *Aparchitocythere, Progonocythere, Leptocythere, Cytherura, Cythereis, Cytherella, Camptocythere, Monoceralina, Ammobaculites, Massilina, Lenticulina, Astacolus, Vaginulinopsis, Dentalina, Nodosaria, Lingulina, Tristix, Vaginulina, Citharinella, Paleopolymorphina,* and *Spirillina.* Though the Foraminifera include a wide variety of genera and are generally well preserved, they are relatively rare in the Curtis formation in the area studied. Ostracods, however, are abundant.

The ostracod genus *Aparchitocythere* is the most abundant and is typical of the Curtis as a whole. Within the Curtis two ostracod zones are recognized. The lower zone contains *Progonocythere,* and the upper zone *Leptocythere* and *Cytherura.* These zones are the same as those provisionally designated in the Swift formation.

The depositional environments of the Curtis formation in the eastern Uinta Mountain area were very similar to those of the Swift formation in southern Montana, eastern Wyoming, and western South Dakota.

POSSIBLE TRIASSIC CHALCOCITE PLACER, RIO ARRIBA COUNTY, NEW MEXICO

J. W. Gabelman and H. G. Brown, III

Box 65, Palisade, Colo.

Secondary copper sandstone deposits are common throughout northern New Mexico in Permian and Triassic sandstones. Normally these deposits offer no conclusive genetic evidence.

A deposit in Triassic Agua Zarca sandstone member at the base of the Chinle formation in Arroyo del Cobre offers fair evidence for a detrital origin. The Agua Zarca is medium- to coarse-grained, moderately arkosic, quartz sandstone with stringers and lenses of conglomerate and mudstone. Quartzite pebbles and clay balls isolated in sandstone are common. Carbonized logs and woody trash are prominent in the bottoms of local channels. Sedimentary features indicate torrential deposition from a braided stream of relatively steep gradient in a broad channel such as those now in the region. The conglomerate is composed of Ortega quartzite derived from the late Paleozoic Brazos Range, possibly less than 15 miles northeast. Primary copper deposits are known in the Precambrian of the present Brazos uplift.

Chalcocite occurs only in conglomerate as rounded grains and nuggets up to 5 inches in diameter (average about half an inch). Malachite, rarely azurite, and limonite form alteration rings around chalcocite nuggets and stain surrounding sand grains. Leached copper is precipitated as carbonate in or around underlying mud lenses and carbon trash.

If the chalcocite nuggets are not detrital, chalcocite must have replaced quartzite pebbles. Open cavities were improbable. The nuggets possibly were preserved by short transport and quick burial, thus counteracting the high solubility of chalcocite.

CHANNEL DEPOSITS OF THE WIND RIVER FORMATION IN FREMONT COUNTY, WYOMING, AS A GUIDE TO URANIUM ORE

Stanley C. Grant

The California Company, Casper, Wyo.

The Eocene Wind River formation, composed of channel deposits and loosely consolidated sandstone, siltstone, and shale, is the host for large quantities of low-grade uranium mineralization in

east-central Fremount County, Wyoming, just north of Beaver Rim. Some mineralization is concentrated enough to be of commercial grade. Seven uranium minerals—meta-autunite, uraniferous apatite, uraninite, uranospinite, liebigite, uranophane, and metazeunerite—have been found in the area. Meta-autunite and uraniferous apatite are the most abundant. These minerals occur as replacements of organic material and carbonate cement and are disseminated through sandstones and conglomerates, in part, as a coating on sand grains and boulders.

The richest ore deposits have been found in bends or at the outer borders of channels, which are believed to be the major control of uranium deposition in the area. Minor structural and stratigraphic features also controlled deposition to a lesser degree.

A possible source for the uranium may have been younger volcanic ash from which the uranium could have been leached by ground water, carried in solution and later precipitated in favorable zones of the channel deposits.

STRATIGRAPHY OF THE TRIASSIC CHINLE FORMATION OF THE SAN RAFAEL SWELL, UTAH

Frederick A. Groth

University of Wyoming, Laramie, Wyo.

Fourteen stratigraphic sections of the Chinle formation were measured at selected intervals along its outcrop around the San Rafael Swell, Utah. A prominent sandstone at or near the base of the Chinle has been erroneously mapped as Shinarump conglomerate. In places this sandstone lies at the base of the Chinle in the northeastern part of the Swell, but when traced to the southern end of the Swell, in the vicinity of the Delta Group mine, it is underlain by as much as 100 feet of Chinle shales and sandstones. This so-called Shinarump conglomerate, therefore, is a medial Chinle unit. The true Shinarump conglomerate is absent, and Chinle rests disconformably on the Moenkopi around most of the Swell. At several places discontinuous sandstone lenses occur at a lower horizon at the base of the Chinle shales and may be equivalent to true Shinarump.

Correlation of units constituting the Chinle around the Swell indicates the existence of a local pre-Chinle "high," over which no Shinarump conglomerate was deposited. The source of some of the sediment in the prominent Chinle sandstone is suggested to be from similar pre-Chinle high areas.

It is suggested that this sandstone, like the true Shinarump, originated on a pedimentlike surface but that the deposits represent two periods of deposition which may be related to different source areas.

CONTROL OF URANIUM DEPOSITION BY GARNET-QUARTZ ROCK IN THE FALL RIVER AREA, CLEAR CREEK COUNTY, COLORADO

C. C. Hawley and F. B. Moore

U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Tertiary vein deposits in the Fall River area, Clear Creek County, Colorado, contain gold- and silver-bearing base-metal ores and locally uranium. The veins cut Precambrian metasedimentary and granitic wall rocks.

Uranium occurs in five veins, but only at the intersections of the veins with garnet-quartz rock layers. The uranium occurs as hard, lustrous pitchblende that was deposited early in the paragenetic sequence, and as soft, sooty pitchblende (of probable supergene origin). Associated metallic minerals are pyrite, chalcopyrite, tennantite, galena, and sphalerite. Gangue minerals are quartz, carbonates, and barite.

The garnetiferous rock contains more than 50 per cent garnet and quartz in approximately equal proportions. Biotite, magnetite, and amphibole are other constituents. This rock is interlayered with biotite gneiss and amphibolite and cut by biotite-muscovite granite and pegmatite. The garnet-quartz rock is pyritized adjacent to the vein; the other wall rocks are silicified and sericitized.

The cause of uranium deposition may have been physical or chemical or some combination of both. The garnetiferous rocks formed a more highly fractured vein zone than did the associated biotite gneiss and amphibolite. A chemical control is suggested by the fact that other competent rocks, such as granite and pegmatite, do not contain significant quantities of uranium at their intersections with the veins.

PRECAMBRIAN ALGAE OF THE MEDICINE BOW RANGE, WYOMING

Frank S. Hensley, Jr.

University of Wyoming, Laramie, Wyo.

Sections have been cut from a sample of a typical quartzitic domed "head" of the Precambrian algae, *Hadrophycus immanis* Fenton and Fenton, 1939, from the Nash marble, Medicine Bow Range, Wyoming. After cutting, the sections were etched in hydrochloric acid. Sections at right angles to the laminae show that the laminae are made up of fine-grained granular quartz, while the less resistant separating interzones are made up of the same type of quartz grains with interstitial carbonate. Sections within the interzone and parallel to the laminae show irregular rods or pillars connecting the laminae. The rods are of the same lithology as the laminae. Samples from an exposure of undomed interbedded dolomite and chert adjacent to the domed "head" were etched, and they show no pillars and less uniformity in the width of chert laminae and the dolomite interzones. The preliminary work done so far suggests that the planar interbedded dolomite and chert in this area have no distinctively organic structure and only remote similarity to the quartzitic dome examined. *H. immanis* should, therefore, be restricted to include only hemispheric forms with some type of pillar connecting the laminae.

PETROGRAPHY OF WYOMING TITANIFEROUS SANDSTONE

Robert S. Houston

U. S. Geological Survey, Geology Hall, Univ. of Wyoming, Laramie, Wyo.

The common heavy detrital minerals present in seven deposits of Upper Cretaceous "black sands" representing all the major structural basins of Wyoming are ilmenite, magnetite, zircon, garnet, rutile, staurolite, monazite, anatase, spinel, and tourmaline in order of abundance. The zircon is uraniferous and is responsible, in part, for the radioactivity of the sandstone. Some of the ilmenite is highly altered. In reflected polarized light the slightly altered material has dark-gray cores of fresh ilmenite surrounded by rims of light-gray granular alteration products. More highly altered ilmenite grains are grayish white in reflected polarized light and are composed of anatase and hematite. Certain zones in the titaniferous sandstone that do not contain many black minerals and appear barren contain more than 15 per cent TiO_2 owing to the presence of these lighter-colored alteration products. The type and degree of alteration of these rocks may have considerable bearing on their value as a possible source of titanium.

STRUCTURAL RELATIONSHIPS AT THE INTERSECTION OF THE MAXWELL AND POORMAN BRECCIA REEF FAULTS, BOULDER COUNTY, COLORADO

A. G. Humphrey

Department of Geology, Univ. of Colorado, Boulder, Colo.

Laramide faults, known as "breccia reefs," are the major structural features exposed within the southeastern portion of the Gold Hill mining district, Boulder County, Colorado. The northwestward-trending Maxwell reef has been displaced by the eastward-trending Poorman reef. The Gold Medal reef and most of the gold-telluride fissure veins strike easterly and appear to be directly related to the Poorman reef.

Precambrian granite and associated pegmatite and aplite dikes are the major rock types, although some Laramide alaskite dikes also occur in the vicinity. Planar structures within the granite commonly trend easterly, and in places the granite has been strongly foliated by shearing parallel to the flow planes. These Precambrian zones of weakness appear to have controlled the locations of many of the Laramide structures.

The observed structural pattern suggests that the formation of the vein fissures is related to movements along the Poorman and Gold Medal breccia reefs. A genetic sequence is outlined for the structures, and some theoretical relationships have been suggested to show the influence of the breccia reefs upon the deposition of ore.

GEOLOGY OF NORTH HAHNS PEAK AREA, ROUTT COUNTY, COLORADO

James M. Hunter

Univ. of Wyoming, Laramie, Wyo.

The north Hahns Peak area comprises 35 square miles in east-central Routt County, Colorado, between the Elkhead Mountains and the Park Range. The area centers around the south two-thirds of T. 11 N., R. 85 W.

The stratigraphic section includes 2600 feet of Mesozoic sediments ranging from the Chugwater formation through the lower 1000 feet of the Mancos shale. These sediments are overlain unconformably by the Miocene Browns Park (?) formation which contains a discontinuous basal conglomerate containing Precambrian boulders. The Browns Park (?) formation consists of medium- to fine-grained, yellow to white, friable sandstone. In the southern part of the area a rhyolite porphyry intrudes the sediments, while in the northwest part a basalt with a circular outcrop pattern suggests an intrusive with numerous associated dikes.

Along the flank of Dome Mountain in the eastern part of the area Precambrian rocks are thrust toward the west. The thrust trends N. 20° W., paralleling the Park Range. The axes of a steeply dipping syncline, a low anticline, and a shallow syncline parallel the Park Range to the west in that order. A westward-trending high-angle scissor-type fault cuts the previous structure at right angles infaulting Mesozoic sediments on the eastern margin.

Most of the folding and faulting in the North Hahns Peak area is Laramide and pre-Browns Park. The intrusive action is all post-Browns Park; however, no evidence of the relative ages of the rhyolite porphyry and the basalt was found.

AREAL GEOLOGY OF THE FOOTHILLS OF THE FRONT RANGE IN NORTHERN COLORADO

Zena M. Hunter

883 Grant Pl., Boulder, Colo.

A map (1/24000) of the areal geology of the foothills between Golden, Colorado, and the Wyoming border presents the following data:

(1) Outcrops of the sedimentary rocks, from the base of the Fountain formation to the Hygiene member of the Pierre formation

(2) Tertiary intrusives into the sedimentary rocks

(3) Structural patterns in the sedimentary rocks of the east flank of the Front Range.

The data have been assembled primarily from Masters' and Doctors' theses of the University of Colorado and from extensive field reconnaissance and aerial photograph study. Other available source material has been used in verification and modification.

POST-LARAMIE SEDIMENTS IN THE SOUTHERN PART OF THE DENVER BASIN, COLORADO

Laurence Kittleman, Jr.

Department of Geology, Univ. of Colorado, Boulder, Colo.

The Dawson and the Castle Rock formations were studied in an area adjacent to the towns of Castle Rock and Colorado Springs, Colorado. The Arapahoe, Denver, and Green Mountain formations of the Denver region were studied to a lesser extent. The investigation included a study of subsurface data, an examination of stratigraphy, the determination of lithologic characteristics from hand specimens and from petrographic thin sections, and a consideration of chronology, as indicated by vertebrate fossils. Depositional environments also were considered.

A new lithologic interpretation and a modified stratigraphic nomenclature are proposed. The Dawson formation and the Denver formation are partly of Late Cretaceous and partly of Paleocene age. The Castle Rock formation is of early Oligocene age. The Dawson formation merges with the Arapahoe, Denver, and Green Mountain formations. It is proposed that the Dawson formation and the Arapahoe, Denver, and Green Mountain formations be considered facies of a single sedimentary

system. The Castle Rock formation overlies the Dawson formation disconformably and is believed to be much younger than the youngest Dawson sediments.

TITANIFEROUS SANDSTONE OF WYOMING AND ADJACENT AREAS

John F. Murphy

U. S. Geological Survey, Geology Hall, Univ. of Wyoming, Laramie, Wyo.

Seventeen lenticular deposits of "black sand" containing up to 33 per cent TiO_2 have been sampled, and nine additional deposits are known. These lie in a discontinuous belt 700 miles long, extending from the Montana-Alberta border to Grand Mesa, Colorado, subparallel to the Rocky Mountains. The largest deposit examined contains about 780,000 tons of rock in sight that averages about 16.5 per cent TiO_2.

The deposits, with one minor exception, are in Upper Cretaceous sandstone apparently transitional between marine and nonmarine facies. A common source area is suggested by the remarkable similarity of the mineral assemblage, which consistently contains several rare elements in significant amounts. The mineral assemblage comprises ilmenite, magnetite, zircon, anatase, rutile, monazite, garnet, tourmaline, and several unidentified heavy minerals. Rare elements are cerium, lanthanum, niobium, neodymium, vanadium, ytterbium, and yttrium. Chemical and radiometric analyses show maxima of 0.020 per cent uranium and 0.056 per cent equivalent uranium.

The source area, if located by use of these minerals and minor elements, would then be more accurately dated as to time of uplift and erosion. The deposits were derived from a western source, possibly the Idaho, Boulder, and other batholithic intrusions.

These deposits demonstrate that the search for economically significant quantities of detrital minerals can be facilitated by recognition of the position of Cretaceous shore lines and adjacent positive areas. Radioactivity, primarily due to fluorescent uraniferous zircon, has led to the discovery of many of these titaniferous sandstone deposits, by both surface prospecting and airborne reconnaissance.

TRACHYBASALT FROM FRESNO COUNTY, CALIFORNIA

George J. Neuerburg and Warren B. Hamilton

U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Near Huntington Lake in the central Sierra Nevada are three peaks formed of Cenozoic trachybasalt and related basalt. Intrusive masses form Black Point and Red Mountain, and Chinese Peak is capped by flows. The Black Point mass, largest of the exposures, is half a mile in diameter. Surrounding rocks are Mesozoic granites.

Most of the trachybasalts consist of granular mosaics of sanidine crystals, densely crowded with microlites and minute granules of plagioclase ($An_{\sim 50}$), clinopyroxene, and magnetite, and abundant phenocrysts and microphenocrysts of olivine and clinopyroxene. Sanidine content ranges from 15 to 30 per cent, and olivine and pyroxene each range from 5 to 25 per cent. The rocks contain a variety of clinopyroxene-sanidine miaroles and ellipsoidal aggregates of clinopyroxene. Many of the larger pyroxene crystals are poikilitic and enclose numerous anhedra of sanidine.

The average of four analyses is $SiO_2 = 54$ per cent, $Al_2O_3 = 14$, $Fe_2O_3 + FeO = 9$, $MgO = 7$, $CaO = 7$, $Na_2O = 3$, $K_2O = 3$, and $TiO_2 = 1$. The one sample analyzed for radioactive elements contains 5 ppm of uranium and 130 ppm of thorium.

Assimilation of granitic materials is indicated by relationships of xenoliths and xenocrysts, but assimilation of granitic rock in a normal basaltic magma with or without normal differentiation is inadequate to explain the characteristics of the rocks. Particularly puzzling are the high contents of magnesia, potassium, and thorium and the low content of alumina.

GEOLOGY OF THE GALENA, SOUTH DAKOTA, AREA

Murray O'Neal and David W. Stearns

South Dakota School of Mines and Technology, Rapid City, S.D.

The Galena district is located along Bear Butte Creek about 11 miles by road southeast of Deadwood, South Dakota. Bear Butte Creek has cut through the gently dipping beds of the Pahasapa,

Englewood, Whitewood, and Deadwood formations into the Precambrian schists. The formations range from Mississippian to Precambrian. The sedimentary formations strike north and dip about 20° E.

All the ore deposits of the district are in the Cambrian Deadwood formation. Nearly vertical fractures, striking principally northeast and east and of varying vertical dimension, served as passages for the Tertiary ore-bearing solutions. The ore was deposited by selective replacement of dolomitic beds in two horizons, the upper near the top of the formation, the lower 20 to 70 feet above the Precambrian.

The Precambrian and Deadwood formations are intruded by a series of Tertiary hypabyssal rocks which range in composition from granite porphyry to monzonite porphyry. All the igneous rocks show extensive hydrothermal alteration. Many of the feldspars are completely altered to clay minerals.

The intrusions are high-angle dikes in the Precambrian but change in the Deadwood formation to sills or very low-angle dikes. The most common igneous bodies in the Deadwood formation are bedding-plane sills. These sometimes change horizons by following nearly vertical fractures to a new horizon. Monoclinal structures are formed in the sediments along the edges of the sills or dikes. Field evidence indicates the intrusions were highly viscous at the time of emplacement.

POZZOLANIC ACTIVITY OF GIBBSITE AND ITS THERMAL PRODUCTS

David Ramaley

Petrographic Laboratory, Bureau of Reclamation, Denver Federal Center, Denver, Colo.

Excellent pozzolanic activity of such silica-alumina combinations as various calcined clays prompted an investigation of compounds of alumina. The studies now reported were conducted on gibbsite ($Al_2O_3 \cdot 3H_2O$) and its thermal modifications.

Differential-thermal and Chevenard thermal-balance curves for gibbsite heated to 1000° C and X-ray diffraction analyses of samples calcined at temperatures within this range indicate the following transformations: gibbsite begins to dehydrate to boehmite ($Al_2O_3 \cdot H_2O$) at about 210° C, and conversion is complete at 380° C; boehmite in turn converts to γ-(or η-) alumina above 425° C; κ-(or θ-) alumina forms at 1000° C.

The pozzolanic activity of gibbsite and its thermal products were evaluated by their effect on compressive strength and autogenous volume change of portland cement mortar. Gibbsite and its thermal modifications produce mortars of unsatisfactorily low compressive strength. Highest strength was obtained with raw gibbsite and lowest with the gibbsite-boehmite mixture developed by calcination at 230° C. Neither raw gibbsite nor κ-alumina effectively control alkali-aggregate reaction. Boehmite and θ-alumina meet the specified requirement for reduction-of-mortar expansion at an age of 14 days, but at greater ages expansion progresses at an unsatisfactory rate. The gibbsite-boehmite combination failed the 14-day requirement, but the relative reduction of expansion increased progressively up to 6 months.

These results suggest that alumina acts jointly with silica to form cementitious compounds with calcium; without available silica, alumina is ineffective as a pozzolan.

ARROYOS AND THE SEMIARID CYCLE OF EROSION

S. A. Schumm and R. F. Hadley

U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Longitudinal valley profiles surveyed in small drainage basins in eastern Wyoming reveal that discontinuous gullies are often developed in areas of local steepening on valley fills. A geomorphic explanation of these gullies leads to the postulation of a semiarid cycle of erosion in which natural arroyo formation apparently plays an important role.

The classical Davisian discussion of the humid and arid geomorphic erosional cycles tends to obscure the possibility of a transitional stage between the two. Studies in some valleys in eastern Wyoming show that as many as one-third of the minor tributaries are not graded to the major drainage channels. This suggests that in these intermittent channels, where sediment load increases downstream faster than discharge, the lack of accordance between tributaries and a larger-order stream

may be common because of alluviation within the tributary channel. Alluviation once begun may continue until the channel is filled. Continued deposition causes local steepening of the fill. Discontinuous gullies form at these points, shifting sediment downstream. The gradient is increased in the lower part of the aggraded reach until a channel forms, allowing reintegration of the tributary with the main drainage channel and trenching of the valley fill.

This hypothesis considers the arroyo problem in geomorphic perspective and is offered primarily as a guide to further work on this complex problem.

PHOSPHATE DEPOSITS IN THE CARIBOU RANGE, BONNEVILLE COUNTY, IDAHO

Richard S. Sears

Phillips Petroleum Company, Salt Lake City, Utah

Phosphate deposits in the northeastern part of the Caribou Range, about 40 miles east of Idaho Falls, are found on the flanks and crestal zone of the northwest-trending Snake River anticline. The deposits are in sediments in the transitional zone between the eastern continental shelf and western miogeosynclinal zones.

The Phosphoria formation (Permian) is about 190 feet thick and consists of the lower phosphatic shale member, about 55 feet thick, and the Rex chert member, about 135 feet thick. The Rex chert-shale member contact is commonly disconformable.

The high-grade phosphate rock zone, 1½ to 10½ feet thick, is at the top of the shale member. Four rock types were recognized: (A) finely oölitic, (B) coarsely oölitic, with a white matrix, (C) fish scale and bone fragment, and (D) blocky, finely detrital. Type A is the most abundant, although type C constitutes most of the float. Types B and D have not been observed elsewhere in Idaho. Lateral variations in this zone occur within very short distances.

Twenty trenches across the shale member exposed numerous structural complications, with minor faulting very common. The unusual variations in total thickness, number of individual beds, and distribution of rock types were probably caused by sedimentary processes rather than by structure.

LOCALIZATION OF METATORBERNITE IN ALTERED WALL ROCKS, CENTRAL CITY DISTRICT, GILPIN COUNTY, COLORADO

P. K. Sims and E. W. Tooker

U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Uranium is a local constituent of the Tertiary gold- and silver-bearing veins in the Central City district, Gilpin County, Colorado. Generally the uranium occurs in primary pitchblende within the veins, but in two areas on the north edge of the district secondary metatorbernite replaces altered wall rocks along the veins. This occurrence of metatorbernite is rare in the United States.

The metatorbernite is associated with galena- and sphalerite-bearing veins that cut folded, interlayered metasedimentary and granitic rocks of Precambrian age. The metatorbernite has replaced altered biotite-quartz-plagioclase gneiss and altered amphibolite wall rocks in the supergene zone; it is absent in other rock types.

Alteration has converted the host rocks for the metatorbernite largely to montmorillonite. Plagioclase altered most easily and was converted to montmorillonite in zones of moderate alteration. With more intense alteration, biotite was bleached and changed to illite and montmorillonite, and the quartz content was reduced. Hornblende was altered to biotite and a mixture of montmorillonite and illite.

Metatorbernite replacing biotite along cleavage planes and crystal margins is concentrated along the edges of pods of completely argillized amphibolite and at contacts between moderately and intensely altered biotite gneiss. Granular metatorbernite is disseminated throughout moderately altered rocks of both types.

The restriction of metatorbernite to the two types of wall rock implies that alteration of these rocks provided an environment suitable for deposition; other generally less altered rocks were not favorable sites for deposition of uranium.

SPECTACULAR DISPLACEMENT OF SNAKE RIVER BY A LAVA FLOW NEAR BLISS, IDAHO

Harold T. Stearns

Box 241, Wahiawa, Oahu, Hawaii

In late Pleistocene an eruption of very fluid porphyritic pahoehoe basalt built a flat dome, called McKinney Butte, 300 feet high and 4 miles across. The flow covers more than 80 square miles and poured into Snake River Canyon, 11 miles away, to form a great mass of pillow-lava breccia (the so-called Bliss cone), which dammed a lake 22 miles long. The lake filled partly with sediments, chiefly clay, before it was drained. The lava reached the rim in a 6-mile stretch upstream from the dam in insufficient volume to fill the canyon, but it spilled as great firefalls down the steep canyon walls to form pseudo dikes and fans of fragmented pillow lava and comminuted glass. Petrographic studies by Andrei Isotoff indicate that the Bliss pillow lava is part of the same lava flow as the McKinney basalt. Long drools of the lava now veneer the talus slope of the canyon wall in a few places. The lava filled Snake River Canyon for 11 miles below the point of entry and caused the river to cut a new canyon along the south margin of the lava. Where the Snake River cascaded down the terminal margin it built a huge fan of boulders, gravel, and sand which is now partly cut away, but long ribbons of boulders still indicate its former main channels. The great volume of rock moved by Snake River and the diverse associated deposits from this single volcanic accident are impressive and indicate the complexities of the geology under the vast Snake River lava plain where many similar accidents may have occurred in late geologic time but which are now buried by subsequent lava flows.

HIGH-LEVEL FOSSILIFEROUS LIMESTONE ON UPOLU ISLAND, SAMOAN ARCHIPELAGO

Harold T. Stearns

Box 241, Wahiawa, Oahu, Hawaii

In 1954 M. G. Irwin discovered a block of limestone weighing more than 10 tons on Upolu Island near Le Fale o le Fe'e in Soaga Canyon at an elevation above 650 feet. The exact elevation is yet to be determined. A barometer reading, made in a rainstorm in 1941 at "Le Fale", was 1500 feet, but no accuracy can be claimed for it. A search is now being made in the heavily forested area for limestone in place, and accurate elevations will be established. J. Harlan Johnson reported recognizable fossil coral somewhat recrystallized in the limestone block but no recognizable algae in thin sections. The find is significant because it is the first high-level limestone reported on any island in the Central Pacific, except in the Hawaiian Islands. If the 10-ton block came from an outcrop close by, it indicates a large emergence of Central Pacific Islands in late geologic time, possibly as a result of eustatic movements much greater than those attributed to glaciation and deglaciation during the Pleistocene.

DISCOVERY OF CRETACEOUS (?) SEDIMENTS IN SOUTHWESTERN IDAHO

Harold T. Stearns

Box 241, Wahiawa, Oahu, Hawaii

A series of buff and light-colored sedimentary silicious tuffaceous beds, thin coal beds, and quartz grits more than 200 feet thick lie in fault contact with highly amygdaloidal brown bedded basalts in Coal Mine Gulch in the north bank of Snake River in the NE1/4 sec. 27, T. 11 N., R. 7 W., B. M. near Weiser, Idaho. The sedimentary beds are one of Kirkham's type localities for the Payette formation (Miocene), and the lavas were classified by him as typical Columbia River basalts. Chaney has described as Miocene a large collection of fossil plants from the same gulch. While mapping the geology of the Weiser and Olds Ferry quadrangles, the writer collected a single flattened fossil freshwater shell from one of the fine-grained beds in the gulch. John B. Reeside, Jr., states that the specimen is a species of *Viviparus* or *Campeloma* which cannot be older than early Cretaceous or younger

than Paleocene. He prefers to consider it late Cretaceous. The determination has reopened the question of the age of the Payette formation and associated basalts. Great erosional unconformities exist in the Weiser quadrangle between the basalts and the so-called Payette formation suggesting that the stratigraphy of southwestern Idaho is older and more complex than Kirkham thought.

ORIGIN OF FULFORD CAVE, EAGLE COUNTY, COLORADO

J. V. Thrailkill

Dept. of Geology, Univ. of Colorado, Boulder, Colo.

Fulford Cave, a solution cave on the northwest flank of the Sawatch Range in Eagle County, Colorado, is in the Mississippian Leadville limestone and may extend into the underlying Devonian Chaffee formation. Erosional and depositional features within the cave indicate that its present form is due to solution and deposition under three distinct environments.

Deep in the phreatic zone, slowly moving ground water dissolved cavities along structurally controlled planes in the rock. Subsequent depression of the water table relative to these cavities brought them into the shallow phreatic zone, where the more corrosive ground water near the water table dissolved conduits parallel to and just below the water table. Further depression of the water table brought these cavities into the vadose zone where their shape was slightly modified by subterranean streams. Ceiling collapse, an important factor controlling the shape of the passages, occurred continuously in all three environments.

At least a portion of the cave has undergone the above progression of environments twice, with the vadose environment being present in both Mississippian and Quaternary time. As the Mississippian vadose stage ended, the cave below the rising water table was filled with clastic debris. Uplift of the area during the Laramide Revolution initiated the present progression of environments, and the fill was flushed out as the water table dropped. Considerable stalactitic material has been deposited during the present vadose stage.

INVESTIGATION OF WALL-ROCK ALTERATION, CENTRAL CITY AND IDAHO SPRINGS DISTRICTS, GILPIN AND CLEAR CREEK COUNTIES, COLORADO

E. W. Tooker

U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Wall-rock alteration along veins in the Central City and Idaho Springs districts, Colorado, resembles that found with vein deposits in other mining districts. Successive, but variable, alteration "envelopes" around the veins generally consist of an inner sericitized and silicified zone and an outer argillized zone. The altered rocks are being studied to determine: (1) the detailed mineralogy of the alteration halo, (2) the relationship between types of alteration and lithology of wall rocks, (3) any differences of the major alteration pattern with respect to the major types of ores, (4) the effect of structure on alteration, and (5) the chemistry of the altering fluids.

The study of the mineralogy of altered rocks where clay minerals are prominent constituents necessitates a careful sampling procedure and special laboratory methods. The collection of representative samples in old mining districts presents many problems: Many mines have been closed for years and have been partly or completely filled with water; fresh working faces are rare; the deeper mines are inaccessible; and crosscuts that expose unaltered rocks are uncommon.

Knowledge of the clay and nonclay constituents of altered and related fresh rock was obtained by petrographic, mineralogic, X-ray, and chemical methods. Oriented clay aggregates on glass slides are useful X-ray-diffractometer samples.

TWO-PLAGIOCLASE ROCKS FROM THE JUDITH MOUNTAINS, MONTANA*

Stewart R. Wallace

U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Some porphyritic intrusive rocks of the Judith Mountains, Montana, contain incompatible mineral phases. Eight specimens of more than 200 examined in a comparative study of the composition,

* Publication authorized by the Director, U. S. Geological Survey.

size, and abundance of phenocrysts contain plagioclase crystals of two different compositions; differences range from 14 to 37 per cent An in single specimens.

In one specimen andesine phenocrysts are mantled with potash feldspar rims, but albite phenocrysts are not. This suggests that the coexistence of the two feldspars is the result of fractionation by mantling, and a plot of their compositions on Bowen's diagram of the system anorthite-albite agrees with this theory.

The incompatible plagioclase phenocrysts in the seven other specimens are not armored by potash feldspar, and fractionation by mantling is not a suitable explanation. Other possible mechanisms are: (1) gravitational crystal accumulation; (2) reaction with inclusions; and (3) mixing of magmas. The specific gravities of the plagioclase crystals, the uniform textures of the groundmass, and the lack of alteration of known inclusions negate the first two alternatives; the two-plagioclase rocks seem best explained as the product of mixed magmas. The mineralogy of the hybrid rocks indicates that the magmas (liquid and contained crystals) involved in mixing were rhyolitic and quartz monzonitic. The mineralogic evidence of mixed magmas is supported by the age and space relationships of different textural facies of rhyolite and quartz monzonite in a composite stock. It is suggested that "mixed rocks" are probably common in areas where successive irruptive phases of a differentiating magma are closely related in time and space.

STRUCTURE AND PETROLOGY OF THE GRANODIORITE ALONG UTE CREEK, CLEAR CREEK COUNTY, COLORADO

John D. Wells

U. S. Geological Survey, Denver Federal Center, Denver, Colo.

The granodiorite exposed along Ute Creek, Clear Creek County, Colorado, is on the northern margin of a batholith correlated by Lovering with the Boulder Creek granite. The granodiorite appears to have been intruded syntectonically, probably near the middle of the first recognized period of Precambrian deformation, which folded the wall-rock gneiss. Structures are continuous from the granodiorite into the country rock and are unrelated to the trend of the contact. The forces that deformed the country rock are thus believed responsible for the lineation and foliation of the granodiorite. A later deformation produced local mortar structure and lineations in the granodiorite. Small, thin inclusions oriented at an angle to the foliation may represent the primary flow structure.

The composition of the granodiorite is shown by a plot of the mineral composition on a quartz-microcline-plagioclase triangular diagram. The most deformed specimens of granodiorite contain much microcline but no hornblende; specimens that are moderately deformed contain less microcline but little or no hornblende; specimens that are slightly deformed contain some hornblende but no microcline.

CORRELATION OF PETROGRAPHY WITH STRESS-STRAIN RELATIONSHIPS IN SANDSTONES

Vladimir E. Wolkodoff

Petrographic Laboratory, Bureau of Reclamation, Denver Federal Center, Denver, Colo.

Correlation of petrography and stress-strain relationships (compressive strength, principal-stress relationship, Young's modulus of elasticity, and Poisson's ratio) is developed for the following rocks: Tapeats, Tensleep, and Navajo sandstones; Ogallala opaline sandstone; and graywackes from California and India. The principal stress relationship for sandstones is curvilinear for lateral stress up to 4000 psi. Arenites of moderate unconfined compressive strength vary widely in strength under triaxial conditions and in elasticity with variation in grain-to-grain articulation or type of matrix. Sandstones of sutured texture show the highest compressive strength (65,000 psi axial stress at 4000 psi lateral stress), whereas sandstones characterized by point-to-point contacts and incompetent interstitial matter rarely exceed 45,000 psi axial stress at this lateral stress. The strength of porous sandstones is inferior even under triaxial conditions.

Young's modulus of sutured sandstones is high (approximately 5.0×10^6 psi), whereas it is low for other types of sandstone unless carbonates or opal are the predominant matrix constituent. For

sandstones cemented by opal and with average compressive strength of 12,450 psi, Young's modulus is at least 6.0×10^6 psi; a similar ratio of elasticity to strength is obtained for glassy igneous rocks. Unless the rock is highly calcareous, porosity of arenites correlates well with Young's modulus. Compared with arenites, graywackes typically are lower in strength and Young's modulus because of argillaceous matrices. However, calcareous graywackes are comparable to average arenites.

The effect of calcite seams and varying amounts of interstitial calcite on stress-strain relationships is discussed.

THRUST FAULTING IN THE WESTERN BLACK HILLS

George R. Wulf

Box 403, South Dakota School of Mines, Rapid City, S. D.

A high-angle eastward-dipping thrust has been identified on the west flank of the Black Hills along the Wyoming-South Dakota State Line in the vicinity of parallel 39°55′ N. The Mississippian Pahasapa formation is thrust over the Pennsylvanian Minnelusa formation along a north-south fault which passes into a steep monoclinal fold to the south. The maximum observed displacement is about 400 feet. Several minor high-angle thrusts accompany this main feature and are subparallel to it. Another set of faults in the area strikes dominantly N. 25° W. These faults are more prominent south and west of the high-angle thrusting but appear to transect the former at several localities. The northwest-trending thrusts are low angle with variable displacements and dips mainly to the west. Associated with the disrupted strata are several gentle anticlines striking N. 50° W. or more or less parallel to the general trend of the Black Hills uplift. These folds are characterized by a steeper northeastern flank. Available evidence suggests that the folding preceded the low-angle thrusting, and the high-angle thrusting followed; all were probably essentially contemporaneous with the major uplifting of the Black Hills.

ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN DURHAM, NORTH CAROLINA, APRIL 7–9, 1955

SOUTHEASTERN SECTION (GSA)

SOME DEPOSITIONAL FEATURES OF PENNSYLVANIAN STRATA IN GEORGIA

Arthur T. Allen

Emory University, Ga.

Pennsylvanian rocks extend from Tennessee and Alabama into the extreme northwestern corner of Georgia and are exposed principally in Lookout Mountain and Sand Mountain. The easternmost exposures known are small isolated areas northeast of Ringgold and on Little Sand Mountain 10 miles northwest of Rome. In all areas except the Durham Basin on Lookout Mountain erosion has removed the upper part of the section, and only the Sewanee conglomerate and Gizzard shale remain. The Sewanee conglomerate forms prominent escarpments which present a good opportunity for detailed study.

The Sewanee member is a highly cross-bedded, flaggy to massive, conglomeratic sandstone with interbeds of coal, shale, sharpstone conglomerates, and varved sandstones.

Thin-section and statistical analysis of size, sphericity, and variance of some of the interbeds are presented. The study indicates that the sediments were deposited in a complex environment which included periodic exposure and induration, rapid deposition, and intermixing of sedimentary types.

Comparisons with similar modern deposits are made in concluding that the sediments are of tidal-flat origin.

GORCEIXITE FROM DALE COUNTY, ALABAMA

J. M. Axelrod, M. K. Carron, Stearns MacNeil, and Charles Milton

U. S. Geological Survey, Washington 25, D. C.

Gorceixite [(Ba, Sr, Ca, Ce, La)(Al, Ti, Fe)$_3$(PO$_4$)$_2$(F, OH, H$_2$O)$_8$] occurs in two localities, a few miles apart, near Ariton, Dale County, southeastern Alabama. It was found in the Bashi marl member of the Hatchetigbee formation, the youngest formation of the Wilcox group (lower Eocene).

At one occurrence the gorceixite forms hard whitish to buff nodules as much as several inches in diameter and is a matrix for minute angular quartz grains and glauconite pellets. The nodules are in the weathered highly fossiliferous glauconitic Bashi marl and are associated with green nodules of nontronite. A chemical analysis of the gorceixite shows a rare-earth content of 7.66 per cent. In the second occurrence the gorceixite occurs as structureless finely granular aggregates.

Complete analysis, with optical and physical properties and X-ray diffraction pattern, is given. The mineral has not previously been reported from North America. Further study of the mineral is in progress.

KLIPPEN IN THE HARRISONBURG QUADRANGLE, VIRGINIA*

William B. Brent and Robert S. Young

Cornell University, Ithaca, New York; Division of Geology, Charlottesville, Virginia

Four klippen occur within the Harrisonburg quadrangle, Virginia. Only the largest, that near Burketown, has been previously mapped. Of the three new klippen, the larger of the two directly east of Harrisonburg is described. This klippe is well exposed on the surface and in quarry faces. The Harrisonburg klippe is the northeasternmost known in the Valley of Virginia.

* Presented with permission of the State Geologist of Virginia

The Harrisonburg klippe is approximately 4500 feet long with a maximum width of 500 feet. As now exposed, the klippe is Edinburg ("Athens") thrust on Beekmantown. The thrust fault is marked in places by 15–18 inches of gouge. Post-faulting deformation is manifested by local intricate folding of the fault surface.

A smaller klippe 1400 feet west of the Harrisonburg klippe has similar stratigraphic relations, but the structural detail is not known.

These klippen apparently are not related to any near-by faulting. More probably they are genetically related to the major Staunton fault, 1.5 miles to the east.

STRATIGRAPHIC REVISION OF THE TRENT MARL OF NORTH CAROLINA

Philip M. Brown

Ground Water Branch, Water Resources Division, U. S. Geological Survey, Raleigh, N. C.

Miller (1910) gave the name Trent marl to Eocene beds containing *Ostrea georgiana* Conrad along the Trent River in North Carolina. In 1926 Kellum placed the formation in the lower Miocene, on the basis of mollusks, supposedly having lower Miocene affinities, from Silverdale, 17 miles southeast of the type locality. The writer questions the advisability of shifting the implied type, or pivotal, locality to Silverdale, because of lithologic differences and the absence of common species.

The Trent has been considered a separate limestone formation which with the Castle Hayne (Eocene) and the Yorktown (late Miocene) constitutes the limestone aquifers currently being investigated co-operatively by the United States Geological Survey and the North Carolina Division of Mineral Resources. Solution of limestone outcrops has been severe, making identification of macrofossils difficult or impossible and obliterating original formational characteristics.

Recognition in wells of sharp subsurface contacts between the Yorktown and Castle Hayne formations, together with additional microfaunal evidence in the outcrop area, indicates that lower Miocene deposits are absent in North Carolina, necessitating the abandonment of the name Trent. Rocks previously included in this formation belong either in the Castle Hayne formation or, less commonly, in the thin overlying Yorktown formation.

CHARNOCKITE SERIES IN THOMASTON QUADRANGLE, GEORGIA*

James W. Clarke

Vanderbilt University, Nashville, Tenn.

In Thomaston quadrangle, Georgia, the Wacoohee belt is bounded by the Towaliga fault on the north and the Goat Rock fault on the south. Within this belt the Woodland gneiss comprises the basement complex. Overlying the basement unconformably is the Hollis quartzite, which is in turn overlain by the Manchester formation. The Jeff Davis granite, a batholithic mass, intrudes the Manchester formation. A broad belt of migmatite borders the intrusive.

Rocks of the charnockite series, from hypersthene gabbro to hypersthene granite, intrude the Jeff Davis granite and associated migmatite. Range of minerals present and range in composition of the plagioclase are in accord with the Bowen concept of liquid line of descent of igneous rocks. The mineralogy indicates a high temperature of consolidation. Garnet coronas are common where plagioclase is in contact with hypersthene, augite, hornblende, biotite, ilmenite, or apatite.

FAUNAL SUITES OF THE APPALACHIAN MIDDLE ORDOVICIAN

G. Arthur Cooper

U. S. National Museum, Washington 25, D. C.

The great wedge of Middle Ordovician sediments occupying various belts of the Appalachians from southern Pennsylvania nearly to central Alabama contains fossils that can be separated into faunal suites each occupying a considerable thickness and a wide geographic distribution. Dif-

* Published by permission of the Director, Georgia Bureau of Mines and Geology

ficulties in correlation in the Appalachians are described, and the facies pattern of the sediments is explained.

Correlation of these suites cannot be accomplished by single guide species; each faunal suite must be fully identified. The faunal suites are: Lenoir *Mimella-Valcourea* suite at the base, followed in ascending order by Lincolnshire *Dinorthis-Sowerbyella* suite, Whitesburg *Ptychoglyptus-Paleostrophomena* suite, the Wardell-Witten *Strophomena-Pionodema* suite, and the *Rafinesquina* suite. The first two faunal suites have been traced into basal red beds in the northern Appalachian belts. This indicates red beds of two ages, the younger ones along the Cumberland Front. The middle suite is the most widespread and includes many exotic European genera. The upper two suites are more closely related to high Black River and Trenton faunas of the Midwest.

ELONGATE MEANDERS OF THE NORTH FORK OF THE SHENANDOAH RIVER

C. C. Fisher

Virginia Division of Geology, Charlottesville, Va.

More than 30 elongate meanders, predominantly on Martinsburg shale (Ordovician), are unusually well developed on the North Fork of the Shenandoah River in the Edinburg and Strasburg quadrangles, Virginia. These meanders have parallel crossovers and a sinuosity of 3.3. Meandering begins where the stream leaves older limestones and dolomites and is associated with decrease in stream gradient. Downstream, the North Fork ceases to meander although it remains on the Martinsburg. Added discharge from Cedar Creek, tributary at this point, may shift the equilibrium from conditions causing meandering. The crossovers exhibit remarkable regularity of orientation, averaging N. 48° W., parallel to a vertical joint set. The orientation of the crossovers is probably determined by the strike of this joint set. At the bends the stream flows roughly along the N. 40° E. strike of the Martinsburg shale; the trend of the meander belt also parallels this direction.

The meanders of the North Fork of the Shenandoah River are inclosed (incised). This is attributed to a single erosion cycle. Meander cutoffs indicate that the river has cut down a minimum of nearly 100 feet since it meandered broadly. Because the meanders grow by lengthening of the parallel crossovers, with the radius of curvature of the bends remaining constant, the development of cutoffs is inhibited; none are being formed today. Unusual lengthening of meanders has given rise to long sloping convex banks and extensive point-bar deposits.

DETERMINATION OF THE ORIGINAL GRAIN SIZE OF METAMORPHOSED DETRITAL SEDIMENTS

Irving S. Fisher

University of Kentucky, Lexington, Ky.

In petrologic study of sedimentary rocks, textures present data on source areas, type of transportation, and depositional environment. Inasmuch as texture is commonly destroyed by recrystallization, students of metamorphic rocks generally lack this fundamental data.

In sillimanite-grade metasediments of the Bethel quadrangle, Maine, it is possible to measure zircon grains and through a calculation of hydraulic equivalents to determine the grain size of the original sediment. This method appears successful in the case of metamorphosed detrital sediments. Knowledge of original sediment grain size plus bulk chemical composition and a study of relict structures give a good idea of the original sediments.

PRE-OCOEE EROSION SURFACE IN THE GREAT SMOKY MOUNTAINS, NORTH CAROLINA

Richard Goldsmith and Jarvis B. Hadley

U. S. Geological Survey, Denver Federal Center, Denver, Colo.

In the eastern and southeastern Great Smoky Mountains of North Carolina, the Ocoee series (Precambrian?) rests unconformably on a plutonic-metamorphic basement complex (Max Patch

and Cranberry granites and Carolina gneiss). The unconformity is obscured by post-Ocoee metamorphism in the southeastern section of the Greak Smoky Mountains, although formations can be traced from an area of low-grade metamorphism southeastward into the area of higher-grade metamorphism.

Basal metasediments of the Ocoee series consist of a thin layer of highly aluminous phyllite and mica schist, interpreted as a reworked residual clay, overlain locally by beds of poorly sorted micaceous quartz conglomerate and feldspathic metasandstone. In a few places metamorphosed remnants of an original weathered mantle can be recognized beneath the basal sediments. Conformably above the basal metasediments a sequence of well-sorted cross-bedded meta-arkose and feldspathic quartzite thickens northeastward and is overlapped southeastward by formations higher in the Ocoee series.

Distribution, composition, and sequence of the basal deposits of the Ocoee series suggest that Ocoee sedimentation was preceded by a period of subaerial weathering on an irregular, but probably subdued topography. The weathered material was redistributed probably by a rapidly encroaching shallow sea.

GEOLOGY OF GROUND-WATER PROBLEMS AT THE SHAWNEE POWERHOUSE, TENNESSEE

Leland F. Grant

TVA—510 Union Building, Knoxville, Tennessee

The Shawnee Steam Plant, the only major structure built by the Tennessee Valley Authority entirely on unconsolidated material, presented several constructional problems unique in the Tennessee Valley Authority system. The powerhouse is built on an articulated raft that floats on the foundation of sand and gravel.

The foundation material is terrace gravel underlain by Cretaceous sand, silt, and lignitic clays. Overlying the sand and gravel is fluvio-glacial clay, silt, sand, and small gravel. Ground-water problems were due to water confined in the sand and gravel bed under artesian pressure. The materials above and below the gravel bed were saturated, but low permeabilities prevented high flows through them.

During construction of the plant ground-water levels were lowered to the base of the gravel bed to prevent serious disturbances of the foundation and excavation by excessive water flows. Around the plant a system of "relief wells" were installed to maintain safe ground-water levels. In the future, the pumping of these wells will prevent excessive pressures from developing under the powerhouse. In the design and construction of these wells the geologic factors were of prime consideration.

STRUCTURAL GEOLOGY OF THE RICHARDSON COVE QUADRANGLE, TENNESSEE

Warren B. Hamilton

U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Structures in the 7½ minute Richardson Cove quadrangle in the foothills of the Great Smoky Mountains of east Tennessee trend east-northeast, and folds are overturned to the northwest. Faults separate the rocks into tectonic blocks, the northwesternmost of which consists of an anticline of unmetamorphosed shales and carbonate rocks of Ordovician age. This block is bounded on the southeast by the Great Smoky fault, which thrusts rocks of the Ocoee series (upper Precambrian) over the Ordovician rocks (R. B. Neuman, 1951). The rocks of the Ocoee series immediately south of this fault are lightly metamorphosed clastics in a faulted synclinorium plunging northeast. Rocks of the Chilhowee group (Lower Cambrian) form small fault blocks between rocks of the Ocoee series and the Great Smoky fault.

The southeast half of the quadrangle is underlain by thick metasiltstones (Ocoee series), separated from the clastics to the northwest by a high-angle reverse fault. The metasiltstone forms a northeast-plunging synclinorium in which most small unfaulted folds die out by intersection with other folds rather than by flattening of limbs.

Metasandstones on Webb Mountain form a klippe truncating structures of the underlying metasiltstones. The klippe is probably part of the Greenbrier thrust plate in the higher mountains to the south.

Rocks of the Ocoee series are of the muscovite-chlorite subfacies of regional metamorphism. Cleavage dips southeastward and increases in strength southeastward. In most of the metasiltstone, cleavage strikes more northerly than does bedding. Movement on some faults accompanied metamorphism, but this metamorphism preceded emplacement of the Great Smoky thrust sheet.

ZINC SULFIDE MINERALIZATION IN THE NORTHERN SHENANDOAH VALLEY OF VIRGINIA

Paul Herbert, Jr., and Robert S. Young

Tri-State Zinc, Inc., New Market, Va.; Virginia Division of Geology, Charlottesville, Va.

Sphalerite mineralization occurs in scattered outcrops of upper Beekmantown dolomite (Ordovician) over an area 50 miles long and 25 miles wide, centered in Rockingham and Shenandoah counties, Virginia. Drilling in the central-western part of this area has proved one ore body and several geologically similar, sparsely mineralized zones.

The three main sphalerite occurrences are: (1) disseminated through beds of coarse "recrystalline" dolomite; (2) with white dolomite in thin fractures; and (3) with white dolomite in breccias. The breccias are the potential ore producers.

The principal metallic mineralization is sphalerite-pyrite, locally with minor galena and microscopic chalcopyrite. The order of sulfide deposition was: (1) pyrite, (2) galena, and (3) sphalerite with chalcopyrite. This mineralization selectively replaces white dolomite-cemented breccias and postdates a period of thrust faulting.

The ore-bearing breccia body is an irregular lens, 700 feet long, as much as 100 feet wide, and more than 700 feet deep. It parallels the strike of the rocks (N. 34° E.) and cuts vertically across the dip (30° E.). Breccia fragments have a rather uniform size distribution, a definite lineation, and within the breccia mass stratigraphic units have moved down. The enclosing beds, though tilted and faulted, show no local folding.

Four breccia bodies are irregularly spaced along the strike. Subsurface data indicate that these breccias may also repeat en echelon in a vertical plane. These indications and the observation that tension was the apparent stress lead the authors to postulate that the breccias are large-scale "chatter" lenses related to the North Mountain fault.

STRATIGRAPHY OF THE MURPHY SERIES AND UNDERLYING FORMATIONS IN NORTHERN GEORGIA

Vernon J. Hurst

Georgia Geological Survey, Atlanta, Ga.

The rocks beneath the Murphy series previously called the Great Smoky formation have been divided into four new formations. The succession of formations in the upper part of the Murphy series has been revised. These changes are based on detailed mapping in the Epworth and Mineral Bluff quadrangles and on the use of well-preserved top-bottom features.

DIKE ROCKS OF CENTRAL-WESTERN VIRGINIA

R. W. Johnson, Jr., and Charles Milton

U. S. Geological Survey, Washington 25, D. C.

An aeromagnetic survey of a 500 square-mile region in Augusta and Rockingham counties, Virginia, has located the dike rocks injected into the Paleozoic sedimentary rocks of the Shenandoah Valley and the mountains to the west. These dike rocks have been accurately mapped and studied petrographically. In the Shenandoah Valley they include teschenite, camptonite, aegerite-syenite, nepheline syenite, spinel-bearing basalt, mica peridotite, and olivine and tholeiitic diabase of probable Triassic age, and peculiar quartzitic syenites. In addition, the dike rocks to the west in Pendleton County, West Virginia (mainly basaltic types), and in Highland County, Virginia (largely rhyolitic), are being studied.

Good magnetic definition of the mafic alkalic rocks made it possible to locate those dikes known

previously and many new ones. The alkalic types and, strangely, the diabases showed little or no magnetic expression.

The alkalic dike rocks in western Virginia are confined to an elliptical area centering near Mossy Creek, in northwest Augusta County. Diabase is not found in this area, but numerous dikes exist beyond. Most of the dikes occupy a northwest-trending joint set.

FOUNDATION CONDITIONS AT THE JOHNSONVILLE STEAM PLANT, TENNESSEE

J. M. Kellberg and C. P. Benziger

Tennessee Valley Authority, Geologic Branch, 510 Union Bldg., Knoxville, Tenn.

The Johnsonville Steam Plant, the first of the Tennessee Valley Authority's post-war steam plants, is on the eastern shore of Kentucky Lake in Humphreys County, Tennessee, approximately 70 miles west of Nashville. Construction was started in May 1949, and the sixth 125,000 kw unit was put into operation in February 1953. Subsurface exploration (139 drill holes and 3 test pits) and detailed study of excavations in the construction area provided information on Paleozoic formations in an area nearly devoid of surface outcrops because of a mantle of Tertiary terrace deposits.

The middle Devonian Camden formation and the overlying upper Devonian Chattanooga shale were involved directly in the construction of the project. Older and younger formations were encountered in exploratory drilling.

Exploration indicated a series of northwestward-trending faults along which large, jumbled blocks of Chattanooga shale are intermixed with the underlying Camden chert and clay. The Chattanooga shale is weathered and decomposed for as much as 6 feet above the contact with the Camden chert, while weathering is practically negligible at the contact with the overlying Tertiary deposits.

Owing to the plastic nature of the basal weathered zone of the Chattanooga shale the major structures were based on the underlying Camden chert to prevent unequal settlement. Though the chert is badly fractured, it has adequate bearing capacity; however, large-diameter piles into the chert were required to resist hydrostatic uplift on the structures.

RELATIONS BETWEEN THE CAROLINA SLATES AND THE CHAPEL HILL STOCK, NORTH CAROLINA

Dewey S. Kirstein, Jr.

Appalachian Sulphides Co., Virgilina, Va.

North of Chapel Hill, North Carolina, a northeast-trending stock intrudes members of the Carolina slates. A group of medium-textured igneous rocks ranging from gabbro to granite intrude a volcanic-sedimentary series.

Field evidence indicates that most of the igneous rocks of the Chapel Hill stock are magmatic. The graded zoning suggests that the slates were incorporated in the intrusive. The transition members between the slates and intrusive rocks do not have all the characteristics of thermally metamorphosed rocks but indicate an additive metamorphic development from the intrusive.

FOUNDATION EXPLORATION AND GEOLOGIC STUDIES AT CHEROKEE AND DOUGLAS DAMS, TENNESSEE

Robert A. Laurence

U. S. Geological Survey, Knoxville, Tenn.

Cherokee and Douglas dams were built by the Tennessee Valley Authority, under a war-emergency schedule permitting only 20 and 13 months construction periods, respectively. Both rest on foundations of carbonate rocks. At both sites, foundation defects were directly controlled by minor features of stratigraphy and structure. At the Cherokee site these were (1) a network of solution channels along joints in two limestone beds in a shale formation, especially at and near minor folds and cross-faults, (2) local deep weathering of calcareous shale beds, especially near the same minor structures, and (3) cavernous dolomite beds on a divide forming the reservoir rim.

Principal defects encountered at the Douglas site were (1) extensive solution openings under the river channel, especially along strike joints, (2) bedding-plane caves developed above thin cherty or shaly beds in the abutments, and (3) deep weathering in and near a deposit of volcanic ash and dolomite filling an ancient sink hole.

Exploration, largely by diamond drills and large-diameter calyx drills, was carried on for 6 months before construction, as well as during much of the construction period, and invaluable geologic data were obtained from grout holes and daily observations in the excavated areas. Final limits of excavation, and methods and extent of foundation and rim treatment, were adapted to the geological conditions to provide safe and water-tight structures.

BRACKISH WATER AND ITS STRUCTURAL IMPLICATIONS IN THE GREAT CAROLINA RIDGE

H. E. LeGrand

U. S. Geological Survey, Raleigh, N. C.

The finding of surficial brackish water in Bladen County, North Carolina, has prompted study of the Great Carolina ridge, known heretofore merely as a wide, southeast-trending uplift of Cretaceous strata of the Atlantic Coastal Plain. Surficial brackish water is unusual in the hinterland, and its chemistry proves it represents artesian water rising to the surface along a fault, through breached clay beds and unconsolidated sands. The fault, trending northeastward, marks the west border of a broad, domed area of brackish ground water west of Wilmington. The area is elongated northeastward, indicating that northeast-trending structures form an impermeable barrier which has retarded the flushing of salty water from the artesian beds.

Microfaunal analysis of cuttings from four wells reaching basement, extending from Conway, South Carolina, through Wilmington to the vicinity of Jacksonville, North Carolina, indicates the absence of the Tuscaloosa formation, the basal outcropping formation of the Coastal Plain. This anomaly implies a Tuscaloosa land barrier along this line and a basin of undetermined proportions to the west. Distinctive littoral and outer neritic facies of the Peedee formation juxtaposed near the surficial brackish water suggests faulting rather than rapid deepening of sediments.

Available evidence, including published results of a magnetic survey, support the existence of complex northeast-trending structures. Contrary to general opinion, the Carolina ridge, containing an undrilled area of 8000 square miles, may have favorable structures deserving attention if oil prospecting is stimulated on the Atlantic Coast.

GLACIAL BOULDERS ON THE ARCTIC COAST OF ALASKA

Gerald R. MacCarthy

U. S. Geological Survey, and University of North Carolina, Chapel Hill, N. C.

Fifty-six erratic boulders, believed to belong to Leffingwell's Flaxman formation, are described in detail. This group, found up to 8 or 9 miles from shore on the raised beaches and tundra near Cape Simpson and Point Barrow, Alaska, includes boulders of diabase, granite, tonolite, pegmatite, quartzite, chert, limestone, and an augen gneiss. Many of them are faceted; some bear distinct striae. Leffingwell's conclusion that the Flaxman formation consists of ice-rafted material is accepted, but it is suggested that the icebergs which brought in the boulders may have originated in the Canadian Archipelago rather than in the Mackenzie Basin, although the boulders do not match a collection of rock samples from Fletcher's Ice Island, T_3. If it ever becomes possible to match these erratics with their source outcrops, we might gain a better understanding of the currents along the coast of Arctic North America.

BASIC DIKE IN THE NEW MARKET LIMESTONE OF WEST VIRGINIA

Virgil I. Mann

Department of Geology & Geography, University of North Carolina, Chapel Hill, N. C.

A basic igneous dike exposed in the Blair limestone quarry at Martinsburg, West Virginia, penetrates middle Ordovician rocks. Originally a basic porphyry, the dike is now highly chloritized and

carbonated. Limestones and dolomites in contact with the dike show no evidence of metamorphism. Its structural relation to the enclosing rocks indicates post-early Ordovician, pre-Triassic igneous activity in the area.

GEOLOGIC DATING BY RADIOCARBON METHOD

Earl W. McDaniel

Georgia Institute of Technology, Engineering Experiment Station, Atlanta, Ga.

Until recently, most dating of events in the Pleistocene and Recent periods has involved the extrapolation of processes still in operation. Radiocarbon dating, however, permits accurate and absolute dating of certain types of organic remains and traces, and the dates obtained have been of considerable geologic significance. The results and implications of some of these measurements are reviewed, and the application of the dating method to the problem of the origin of petroleum is discussed.

Tentative plans for the establishment of a Radiocarbon Dating Laboratory at the Georgia Institute of Technology are announced, and a description of the proposed facility is given.

SOME OLD CHESTER PROBLEMS IN THE EASTERN BELT OF OUTCROP

Arthur C. McFarlan and Frank Walker

University of Kentucky, Lexington, Ky.

A. C. McFarlan, David Swann, Frank Walker, and Ed Nosow have restudied the lower Chester in western Kentucky. Surface outcrop was studied to justify, or otherwise, the subsurface correlations of Swann and Atherton (1948) and others. Agreement was reached on the validity of the correlations of these subsurface workers. This involved primarily the conclusions that:

(1) The Bethel sandstone is Mooretown of Indiana instead of Sample.

(2) The Big Clifty sandstone is middle Golconda instead of Cypress. The latter is the equivalent of the Indiana Elwren.

(3) The Beech Creek limestone is lower Golconda instead of upper Paint Creek.

The authors have continued these studies in the eastern belt of outcrop along the western border of the Eastern Coalfield, where:

(1) An extensive bed of crinoidal to oölitic rock is referred to the Reelsville-Beech Creek on the basis of the occurrence of *Aggassizocrinus* and a large crinoid stem of uncertain identity. It is known from the Ohio River to the Tennessee line and is a well-defined zone.

(2) The Pencil Cave is Hardinsburg.

(3) The Indiana Golconda (Haney) is recognized below the Pencil Cave.

(4) The horizons of the Sample sandstone and the Mooretown sandstone are represented in limestone conglomerates and shale breaks.

(5) In much of Rowan and Menifee counties the Ste. Genevieve limestone is missing, and the Renault (Paoli) rests on the St. Louis or the Waverly. This is in the southern part of the area where the Ste. Genevieve is very sandy.

ANCIENT MONAZITE PLACER

John B. Mertie, Jr.

U. S. Geological Survey, Washington 25, D. C.

A band of iron ore, ranging from 12 to 20 inches thick, crops out along the southwest side of Route 687, about 5.4 miles S. 19° W. of Martinsville, Henry County, Virginia. The country rock at this site is shown on the geologic map of Virginia as Wissahickon schist. Most of the rocks in this vicinity are schists that consist mainly of biotite, kyanite, and quartz in varying proportions, with some feldspar. The rock along the hanging wall, though generally recrystallized, contains subrounded detrital grains of kyanite and other minerals, with limonitic rims.

The iron ore varies in composition but consists approximately of 69 per cent magnetite, 15 per cent ilmenite, 9 per cent monazite, 3 per cent zircon, 2 per cent corundum, with 2 per cent of quartz and other minerals. The ore is banded and contains well-rounded grains of monazite and zircon. Corundum occurs sparsely as shattered anhedra intergrown with iron ore. The sedimentary origin of both the ore and the adjacent country rock seems reasonably certain.

Monazite and zircon, separated from the ore, were found to have ages of 770 and 510 megayears respectively. The general magnitude of these ages proves that these minerals were eroded from Lower Cambrian or Precambrian rocks. Such determinations, however, do not indicate the age of the ore deposit.

DEPTH OF ROCK DECAY IN THE ASHEVILLE BASIN

Berlen C. Moneymaker

Tennessee Valley Authority, 510 Union Building, Knoxville, Tenn.

Bedrock in the Asheville Basin is nearly everywhere deeply weathered. Exploratory core borings made at seven dam sites on the French Broad River and its tributaries upstream from Asheville, North Carolina, have shown that the rock is almost completely decayed from the surface down to depths as great as 88 feet, and that it is conspicuously weathered down to depths of 116 feet. As the sites explored are in ! alities where rock conditions appear to be the best available, the maximum depths of decay and conspicuous weathering are not representative of the Asheville Basin as a whole.

All the sites are on crystalline rocks and include the Carolina gneiss, the Brevard schist, and the Henderson granite. Of these rocks, the Carolina gneiss is the most deeply decayed, but the Brevard schist is conspicuously weathered to greater depths than the other rocks. There is, however, considerable variation in the depth and character of the weathering from site to site in rock of the same type. In general, the completely decayed rock, to which the term *saprolite* has been applied, has the texture and much of the general appearance of the original rock. It is a weak material and is easily excavated with pick and shovel. The conspicuously weathered rock varies widely. Much of it is excellent for foundation purposes and requires little or no remedial treatment.

APPLICABILITY OF STUDIES OF RECENT FORAMINIFERA FROM THE FLORIDA KEYS AREA TO TERTIARY FORAMINIFERA

Wayne E. Moore

Virginia Polytechnic Institute, Blacksburg, Va.

Data on the relative abundance of benthonic foraminiferal families and genera permit the best comparisons between foraminiferal environments of the Florida Keys area where calcareous sediments are accumulating and other lithofacies and early Tertiary environments. Bathymetric zones in which lower Tertiary sediments accumulated can be inferred with reasonable experimental error by comparing the relative abundance of benthonic families and genera with similar Recent data.

Foraminifera live in the following environments in the Florida Keys area: Florida Bay, water 0–10 feet deep; the back reef, water 15–30 feet deep; the reef, locally awash at low tide; and the forereef, water deeper than 30–40 feet.

The Florida Bay environment is characterized by great variations in frequency of the Miliolidae, Peneroplidae, Nonionidae, and Rotaliidae, and the absence of the Amphisteginidae, Textulariidae, Lagenidae, and Buliminidae; *Rotalia beccari* is confined to Florida Bay. Variations in the Florida Bay fauna suggest sorting. The Amphisteginidae and Buliminidae are present in the back reef but not in Florida Bay. *Quinquiloculina tricarinata*, *Cribroelphidium*, and *Sorites* are confined to the back-reef environment. The Peneroplidae and Amphisteginidae are most abundant, and the Nonionidae are least abundant on the outer reef patches. The forereef environment is characterized by the appearance of the Cassidulinidae and the rise of the Anomalinidae to a position of minor importance. *Angulogerina*, *Bulimina*, *Uvigerina*, *Siphogenerina*, and *Reusella* are present at depths greater than 150 feet.

GEOLOGIC CONDITIONS IN SOUTH FLORIDA AS RELATED TO ENGINEERING FEATURES

Victor E. Muse

U. S. Corps of Engineers, Jacksonville, Fla.

Much of the Central and Southern Florida Project is located in the Everglades. The plan of improvement includes both agricultural and conservation areas and drainage canals. The flow of water will be controlled by pump stations, gated spillways, and levees and canals. Because of high permeabilities, the control structures must be designed to handle a great amount of underseepage.

The geology of South Florida as applied to engineering considerations is mainly limited to Pleistocene formations. Fluctuations of the sea level during that period resulted in the deposition of alternating and lenticular layers of limestone, sand, and marl. Solution became a dominant factor when sea level was at low stands, resulting in some remarkable permeabilities and porosities.

The design of structures is affected by the geology and permeability at the proposed site. Unwatering of excavations is difficult in some localities because of the presence of highly permeable hard rock interbedded with loose sand.

HEAVY MINERALS FROM GRAYWACKES OF THE OCOEE SERIES, GREAT SMOKY MOUNTAINS, TENNESSEE

Robert B. Neuman, Dorothy Carroll, and Howard W. Jaffe

U. S. Geological Survey, Washington 25, D. C.

Examination of heavy minerals from saprolite of sedimentary rock was suggested by Mertie's report of 1954 on heavy minerals obtained from saprolite formed from granite. Saprolite of feldspathic, poorly sorted, dark sandstones, termed graywacke by Keith in 1895, of the Ocoee series (Precambrian ?) in the Great Smoky Mountains of eastern Tennessee was sampled. Nineteen samples were collected from different parts of the section and from different geologic occurrences. Preliminary concentrates were made of 10 samples with the gold pan; the remainder were concentrated in the laboratory.

Zircon makes up 90 per cent or more of the concentrate of nonopaque minerals in 14 of the samples, and, other than an occasional grain of anatase or rutile, tourmaline forms the remaining few per cent. In only one sample is tourmaline more abundant than zircon. Most of the zircon is rounded, and purple, with fewer colorless and metamict grains. The tourmaline is angular and brown and green. Opaque grains constitute more than half the heavy-mineral concentrate in some samples; of these, brown grains are largely titaniferous, and other black, irregularly shaped grains were probably derived from pyrite.

In three of the six samples fresh, clear zircon was separated from the dull brown, metamict zircon by means of slightly differing magnetic response. In all three samples the ages of the fresh zircon differed from the metamict zircon. Age determinations ranged from 620 to 1160 million years for different samples. Grouping of the age determinations suggests that the Ocoee series received zircon from several sources.

Chemical weathering that produced the saprolite may have destroyed some minerals. Nevertheless, the suite is remarkably simple, indicating perhaps that the original sediment contained a very simple mineral suite or that some mineral species have been selectively dissolved during geologic time.

PHYSIOGRAPHY AND GEOLOGY OF CLARKE COUNTY, GEORGIA

Eldon J. Parizek

University of Georgia, Athens, Ga.

Clarke County, a roughly quadrilateral area in the Piedmont Province of northeast Georgia, is drained by two meandering branches of the Oconee River entrenched into an upland flat. Two levels occur below the old surface. Knick points along small tributaries form shoals and cause up-

stream flats and terraces. Widespread "stone lines" may indicate nonresidual surface materials over much of the region.

Metasedimentary schists and gneisses, migmatites, granites, and hornblende-plagioclase gneiss occur in the area. Thin layers of garnetiferous quartzite and several diabase dikes are also present. Mineral assemblages characteristic of the amphibolite and epidote amphibolite facies identify the metamorphic grade. Varieties of metasedimentary rocks include mica-plagioclase gneiss, muscovite-biotite schist, sillimanite-kyanite schist, sillimanite-garnet schist, and staurolite-mica schist; granitic rocks include strongly contorted biotite granodiorite and an essentially nongneissic muscovite-biotite granodiorite with related pegmatite.

A regional northeast-trending axis of deformation is transected by north-northwest-trending folds. The most pronounced transverse folding is reflected in a doubly plunging anticline formed in contorted biotite granodiorite and adjoining metamorphic rocks. Two shear zones trending northeast and northwest developed during the deformation.

The metamorphic rocks and gneissic granodiorite are probably Precambrian. Muscovite-biotite granodiorite is definitely younger and may be associated with late Paleozoic Appalachian orogeny. Diabase dikes are believed to be Triassic (?).

GRANITES AND PHYLLITES OF SOUTHEASTERN PIEDMONT OF VIRGINIA AND THEIR RELATION TO THE TECTONIC MAP OF THIS AREA*

Arthur A. Pegau and William B. Brent

Division of Geology, Charlottesville, Va.; Cornell University, Ithaca, N. Y.

The area discussed embraces about 2500 square miles in the southeastern Piedmont of Virginia. The prevailing rock type is a granitized schist-gneiss complex, the next most abundant rock is granite, and the third most abundant is phyllite.

The granite, in roughly lenticular bodies striking a little east of north, is of three general types: (1) a gneissose, medium-textured light-gray rock in the western part of the area; (2) a porphyritic pink feldspar rock in the southern and central part of the region; and (3) a coarse-grained, even granular pink feldspar rock in the northeastern part of the area.

There are four bodies of phyllite, presumably of volcanic origin, in the area: (1) in the southwestern part of the area, part of the Virgilina series; (2) in a narrow strip extending from the State line to Lawrenceville and striking slightly east of north; (3) east of the second body and extending from the State line to Ante; and (4) in the northeastern part of the area, striking northwest parallel to and near the border of a granite body.

The bodies of granite and phyllite appear to fit into the southeastern Piedmont Virginia portion of the tectonic map of United States (1944).

OSGOOD (NIAGARAN) BRYOZOANS FROM THE TYPE AREA†

T. G. Perry and Donald E. Hattin

Indiana University, Indiana Geological Survey, Bloomington, Ind.; Indiana University, Bloomington, Ind.

At Osgood, Indiana, a rich bryozoan fauna has been collected from the upper 5 feet of the Osgood (Niagaran) formation at the Ripley County Construction Company quarry in the SW¼SW¼ sec. 22, T. 8 N., R. 11 E. A few species in the assemblage have hitherto not been recorded from these beds. The bryozoans are associated with brachiopods, trilobites, corals, cystoids, nautiloids, and abundant arenaceous foraminifers. The fossils are embedded in gray, highly calcareous shale that contains thin beds of gray, coarse-grained, argillaceous limestone.

Most of the bryozoan specimens belong to the genus *Fistulipora* McCoy and have been assigned to six species, five of which are new. Variation in the form of the lunarium and in the arrangement and number of interzooecial vesicles are specific characters. Consequently, Osgood species of *Fistulipora* can be identified most readily from tangential sections. The structural variability displayed

* Presented with the permission of the State Geologist of Virginia

† Publication authorized by the State Geologist, Indiana Geological Survey

in longitudinal sections is too great for specific differentiation. Three species of the second most abundant genus, *Monotrypa* Nicholson, are recognized, of which one is new. Other bryozoan genera in the fauna include: *Hallopora* Bassler, *Hennigopora* Bassler, *Cheilotrypa* Ulrich, *Pachydictya* Ulrich, *Ceramopora* Hall, *Trematopora* Hall, *Cyphotrypa* Ulrich and Bassler, and *Stigmatella* Ulrich and Bassler; the last two have not been previously reported from the Osgood. Specimens of fenestelloid bryozoans are rare and poorly preserved.

ORIGIN OF THE LAND-PEBBLE PHOSPHATE DEPOSITS OF FLORIDA DETERMINED FROM THEIR CLAY-MINERAL CONTENT

Richard G. Petersen

U. S. Geological Survey, Denver Federal Center, Denver, Colo.

The phosphate deposits of the land-pebble district in Polk and Hillsborough counties, Florida, occur in unconsolidated sand, clay, and phosphorite sediments of doubtful age and origin that overlie the Miocene Tampa limestone and Hawthorn formation. A study of the clay-mineral content of these formations shows:

(1) Samples of the lower Miocene Tampa limestone that contain fresh-water fossils also contain attapulgite or a mixture of attapulgite and montmorillonite. In the samples that contain marine fossils, the clay minerals are illite or montmorillonite or a mixture of the two.

(2) All samples of the overlying middle Miocene Hawthorn formation contain marine fossils associated with montmorillonite or a mixture of montmorillonite and illite. No fresh-water fossils were found in the Hawthorn; however, in the top 30–40 feet of this formation attapulgite is associated with dolomite. The Hawthorn formation contains phosphorite nodules very similar to the phosphorite nodules in the overlying phosphate deposits.

(3) The clay minerals in all samples of the unconsolidated sand, clay, and phosphorite sediments overlying the Hawthorn consist of attapulgite, montmorillonite, or a mixture of the two.

Because of these associations and because the recent work of clay mineralogists has shown that the presence of attapulgite in sediments suggests a fresh-water environment during deposition, the writer tentatively concludes that:

(1) The data presented support the recent theories that a lacustrine environment is necessary for the formation of attapulgite.

(2) The land-pebble phosphate deposits in part, if not entirely, were formed by the reworking of Hawthorn phosphate in a fresh-water environment.

ORIGIN OF THE YORKVILLE GRANITE, NORTH CAROLINA AND SOUTH CAROLINA

Donald B. Potter

U. S. Geological Survey, Hamilton College, Clinton, N. Y.

Part of a Late Paleozoic (?) granitic body in the central Piedmont of North Carolina and South Carolina was mapped during the U. S. Geological Survey's study of kyanite. This study and a reconnaissance by W. R. Griffitts indicate a body 55 miles long between York, South Carolina, and a point 8 miles east of Lincolnton, North Carolina. Although named Yorkville granite by Keith and Sterrett, the rock is a granodiorite. The main body is generally conformable with country rocks and contains abundant septa of metamorphic rocks.

Southeast of Kings Mountain the granodiorite is in the east limb of a major plunging fold. Sillimanite quartzite and manganiferous schist on the east limb persist as septa in the granodiorite; their relative stratigraphic position corresponds to that of kyanite quartzite and manganiferous schist on the west limb. Although the septa could represent ungranitized remnants, the following evidence suggests that the granodiorite crystallized from an intruded magma: (1) the grade of metamorphism in rocks southeast of Kings Mountain increases toward the granodiorite, (2) major folds and foliation in the metamorphic rocks are locally warped to parallel the granodiorite contact, (3) pegmatite dikes, genetically related to the granodiorite, cut the country rocks, and (4) in the granodiorite, zoned plagioclase and an interstitial aggregate of sodic plagioclase, quartz, and micro-

cline suggest a crystallization sequence. Mineralogy and texture of the granodiorite differ distinctly from those of the country rock; gradations between the two were not found.

Assimilation near some high-alumina septa and limited introduction of sodic plagioclase, quartz, and microcline into some septa of biotite schist are indicated.

SUNNILAND OIL FIELD OF COLLIER COUNTY, FLORIDA

Albert C. Raasch

Humble Oil & Refining Co., Tyler, Texas

The Sunniland oil field, approximately 90 miles west-northwest of Miami, Florida, was discovered in 1943 by the Humble Oil and Refining Company. On June 1, 1954, there were 12 pumping wells in the field producing 1521 barrels of oil daily. Cumulative production on the same date was 3,525,877 barrels. Oil is produced from the Sunniland formation (Comanche Cretaceous) at depths ranging between 11,500 to 11,600 feet.

The producing structure is a broad asymmetrical northwest-southeast-trending anticline with slight "nosing" on the southeast flank and local closures on the crest. The surface and subsurface formations penetrated at Sunniland include those of the Coahuila or Comanche, Comanche, Gulf, Paleocene, Eocene, Oligocene, Miocene, and Pleistocene series. Almost all these formations are composed of limestone, dolomite, and anhydrite with small amounts of sand, shale, gypsum, and salt.

MODEL STUDY OF SALT-WATER INTRUSION

Paul H. Shea and Harry E. Whitsett

U. S. Corps of Engineers, Jacksonville, Fla.

A small sand model was set up to investigate the factors determining the extent of salt-water intrusion along a sea coast into a nonartesian aquifer with a horizontal impervious floor. The investigation was limited to the steady-flow case and homogeneous aquifers. The effects of varying the head, the permeability of the aquifer, and the depth of the aquifer were determined.

A relationship was developed from which the position of the salt front can be predicted from the water-table elevation at a point a known distance from the coast. It is emphasized that the relationship is valid only for the conditions of steady flow and a homogeneous aquifer. The accuracy of predictions based on that relationship would depend on the extent to which field conditions reproduce the assumptions on which the formula is based. Engineering applications would be in the planning and design of water supply and water-control works in coastal areas.

POST-PALEOZOIC STRATIGRAPHY OF WESTERN TENNESSEE AND ADJACENT AREAS OF THE UPPER MISSISSIPPI EMBAYMENT*

Richard G. Stearns and Clarence A. Armstrong

Tennessee Division of Geology, Nashville, Tenn.; U. S. Geological Survey, Memphis, Tenn.

As part of a continuing study of the geology and ground-water resources of western Tennessee by the U. S. Geological Survey and the Tennessee Division of Geology, the Upper Cretaceous, Paleocene, and Eocene beds of the Upper Mississippi Embayment were subdivided into five units on the basis of electric logs of scattered wells. These divisions are believed to approximate time-rock units as follows:

(1) Base of gravel, loess, and alluvium to base of "500-foot" sand	Upper and Middle Eocene
(2) Base of "500-foot" sand to base of "1400-foot" sand	Lower Eocene
(3) Base of "1400-foot" sand to top of Cretaceous	Paleocene
(4) Top of Cretaceous to "X Point"	Cretaceous above "X Point"
(5) "X Point" to top of Paleozoic rocks	Cretaceous below "X Point"

* Presented with permission of Director, U. S. Geological Survey

The "X Point" is a horizon in the Cretaceous Selma chalk and clay section which was traced by characteristic "kicks" on the electric logs.

On the basis of samples and electrical characteristics three depositional types were differentiated: back-beach beds, shallow-water near-shore sands, and deeper-water beds. Relationships of these types are shown best by a three-dimensional panel diagram of the units.

Isopach and sand-distribution maps for the five units illustrate the relationship of sand distribution to environment.

Structure contours have been drawn on the top of the Paleozoic, the top of the Cretaceous, and the base of the Middle Eocene.

CAROLINA SLATE BELT

Jasper L. Stuckey
N. C. State College, Raleigh, N. C.

The Carolina Slate Belt embraces a region along the eastern edge of the Piedmont Plateau that ranges in width from 8 to 50 miles and extends northeast-southwest across the State. The rocks of the region, because of their complexity and well-defined cleavage, have been called "slates," but the name is misleading and confusing. They consist of a great volcanic-sedimentary series, made up of bands of slatelike rock interbedded with lenses and bands of volcanic, fragmental, and flow material. The slatelike rock consists of volcanic ash and land waste, while the volcanic, fragmental, and flow materials consist of acid and basic ash, tuffs, breccias, and lava flows. The acid rocks are rhyolitic, while the basic rocks consist of andesitic tuffs, breccias, and flows. The whole series has been metamorphosed and contains a well-defined cleavage, which strikes northeast-southwest and dips steeply northwest.

GEOLOGICAL SIGNIFICANCE OF "STACKED" MEANDERS

William F. Tanner
Florida State University, Tallahassee, Fla.

Streams may meander simply or complexly for short distances. Such anomalous meanders may be described as "stacked." For the field geologist or the air-photo analyst, these anomalies are of considerably more interest than is normal stream behavior. Several factors may be responsible for the anomalous condition:

(1) accelerated erosion of locally soft banks;
(2) resistant lenses (*i.e.*, clay plugs);
(3) nonalluvial formations:
  a. channel-bed bedrock
  b. foothills bedrock
  c. talus
  d. glacial debris
(4) geological structure;
(5) engineering structure;
(6) confluence with another stream.

(Items 1, 2, 3b, 3c, and 3d were suggested by Matthes, 1941.) Item 1 is generally responsible for modification of a single loop rather than an entire meander train. Items 2, 5, and 6, where responsible for "stacking" of meanders, can be identified easily. Items 3b, 3c, and 3d can be ignored (*i.e.*, Item 3d on the Gulf Coastal plain) or identified. Only Items 3a and 4 remain; these are features of considerable interest in stratigraphic and structural mapping. Item 3a is much more common than Item 4.

The reliability of this criterion may be evaluated in terms of certain dimensionless numbers having to do with meander belt and stream widths and lengths (*i.e.*, tortuosity ratios).

EXPLORATION AND ECONOMIC ASPECTS OF SHEET-MICA PEGMATITES IN THE SOUTHEASTERN STATES

Kefton H. Teague

U. S. Geological Survey, Knoxville, Tenn.

Pegmatites that contain coarse book mica represent a unique type of mineral deposit. Most economic deposits occur as shoots within specific zones. Normal exploration practices are difficult, as in most mineral deposits of the vein type, but methods developed in the last 15 years assist greatly in the geologic and physical search for economic deposits of all pegmatite minerals.

Methods of exploration are determined by topography, rock conditions, relation of pegmatite to enclosing rocks and the present land surface, and extent of previous workings, if any. Preliminary exploration of pegmatites generally consists of pits, trenches, stripping, or core drilling. Generally, existing openings are reconditioned and used to explore idle mines. Before either core drilling or rehabilitation of existing openings, consideration should be given to prevailing economic conditions, mine ownership, and mine operator when the mine was abandoned. Reserve estimates on the book-mica content of virgin pegmatites are difficult, and rarely can one give more than inferred reserves. However, careful detailed geologic study of such pegmatites in many instances indicates the best part of the pegmatite for physical exploration, and, indeed, the grade of ore within a shoot often can be computed to determine if physical exploration is warranted at all.

Sheet-mica mining is a relatively risky venture, but some rich mines have shown a large margin of profit. Usually successful sheet-mica mining in the United States has been confined to periods of extremely low labor costs or periods when the price of sheet mica was subsidized.

TAXONOMY OF THE LARGER AMERICAN UINTATHERES

Walter H. Wheeler

University of North Carolina, Chapel Hill, N. C.

The valid genera and species of the large Eocene uintatheres from western United States have been sorted from the many proposed by Marsh and Cope (and others) and their types cited. Three genera are recognized from the middle and upper Eocene: *Uintatherium* Leidy, 1872, is a large middle Eocene form with a mesocephalic skull. *Tetheopsis* Cope, 1885, a very large form from the uppermost middle Eocene and lowermost upper Eocene, has a dolichocephalic skull. *Eobasileus* Cope, 1872, from the upper Eocene, is the largest uintathere known and has the most dolichocephalic skull. One variable species of *Uintatherium*, *Uintatherium anceps* (Marsh) 1871, can be demonstrated. Two species of *Tetheopsis* are indicated: *Tetheopsis ingens* (Marsh) 1885 has a much shorter snout than the type species, *Tetheopsis speirianus* (Osborn) 1881. There is probably but one species of *Eobasileus*, *E. cornutus* (Cope) 1872.

ABSTRACTS OF PAPERS PRESENTED AT THE SIXTH ALASKA SCIENCE CONFERENCE (AAAS), COLLEGE, ALASKA, JUNE 1–4, 1955

GRANITIC ROCKS OF NORTHERN BRITISH COLUMBIA AND SOUTHERN YUKON—SOME REGIONAL ASPECTS*

James D. Aitken
Geological Survey of Canada, Ottawa, Ontario

Undated granitic bodies in northern British Columbia and southern Yukon other than those showing characteristics of Tertiary intrusions are commonly assigned to the Coast intrusions, and a Late Jurassic or Early Cretaceous age is assumed. In view of the existence of granites dated as pre-Permian and as probably pre-Early Jurassic, and the widespread presence of granitic debris in Upper Triassic and Lower Jurassic conglomerates, the foregoing assumption of age is in many instances questionable.

Factors hampering the recognition of pre-Upper Jurassic bodies are: (1) the tendency for granitic bodies of different ages to occupy the same zone; (2) the abundance of undated volcanic rocks in the Mesozoic section; (3) the occurrence of many granitic bodies in areas of Paleozoic rocks only; (4) the effectively identical character of some Jura-Cretaceous granites and older granites; and (5) the absence or near absence of Mesozoic rocks from the axis of the Coast Range. Dating by radioactivity may in the future unravel this problem.

A widespread group of leucocratic granites and quartz monzonites invariably cuts "typical" Coast intrusions. Members of this group have been dated as pre-late Late Cretaceous. The clearly post-tectonic character of the group suggests that they should be distinguished from the Coast intrusions.

The last two phases of plutonic activity are represented by sodic syenite and granite and by granophyric intrusions of normal composition. Members of both these groups are known to cut Paleocene beds, but are not dated with respect to one another.

PERMAFROST, OXIDATION PHENOMENA, AND HYDROGEOCHEMICAL PROSPECTING IN THE MAYO AREA, YUKON†

R. W. Boyle
Geological Survey of Canada, Ottawa, Ontario

The Mayo area is in the region of permanently frozen ground, but the permafrost is patchy in its distribution, depending upon the elevation, hillside exposure, depth of overburden, amount of covering vegetation, and presence of moving underground and surface waters. Ice veins in faults and ore veins are a common feature of the Mayo area and have been observed at depths of 300 feet or more in the mines.

Oxidation of the lead-zinc-silver veins of Keno and Galena hills has been studied in detail. Oxidation effects occur in all veins and have been noted at depths of 500 feet or more from the surface. It is apparent that much of the oxidation in some veins took place prior to the present permafrost because ice veins occupy the solution channels which were probably the courses the meteoric waters followed during the early period of oxidation. In other veins meteoric waters are circulating freely both below areas sealed by permafrost and areas free of permafrost, and oxidation is proceeding at the present time.

Near-surface and deep oxidation of the veins yields heavy metals (principally zinc) to surface and underground waters. A detailed hydrogeochemical survey of stream and spring waters in the Keno Hill-Galena Hill area indicates that most lead-zinc-silver deposits produce heavy-metal anomalies in the streams and springs in their vicinity. Results of this survey show that hydrogeochemical prospecting is applicable in some permafrost areas.

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AEROMAGNETIC SURVEYS ACROSS THE KOYUKUK GEOSYNCLINE AND BETHEL BASIN, WEST-CENTRAL ALASKA

W. J. Dempsey
U.S. Geological Survey, Washington, D.C.

Ten thousand miles of aeromagnetic traverses were flown by the U. S. Geological Survey in the Territory of Alaska during 1954, mainly across sedimentary basins. Depths to the crystalline rocks producing these anomalies have been determined from three pronounced anomalies in the surveyed area of the Koyukuk geosyncline. From southeast to northwest these depths were 4500 feet, 25,000 feet, and 2500 feet. A basin 25,000 feet deep in the center and less than a mile deep along the southeastern and northwestern flanks is indicated. The magnetic data suggest volcanic material at shallow depths near the northwest flank.

The data in the Bethel basin area indicate the crystalline basement is at a depth of about 4000 feet in the northwest and about 6500 feet in the southeast. Near the Tundra River depths of 3–3½ miles were obtained. However, the magnetic data suggest that high-susceptibility material, probably volcanic flows, is present at depths of 1000–3000 feet below the surface so that depth determinations to the basement are less exact.

VERTEBRATE PALEONTOLOGICAL RECONNAISSANCE OF THE OLD CROW RIVER AREA, YUKON TERRITORY, CANADA

Otto Wm. Geist
University of Alaska, College, Alaska

Pleistocene mammal fossils were collected along the Old Crow River during a 1-month boat trip from its mouth near Old Crow Village to its headwaters at Ammerman Mountain and return, a total distance of more than 700 river miles. The trip was financed by the exploration fund of the Explorers Club of New York.

The Old Crow Flats constitute an Arctic lowland dotted with a myriad of lakes, some of which are strikingly oriented N. 45°E. The lowland is floored with perennially frozen Quaternary silt deposits 10 to more than 150 feet thick.

Most of the fossils collected had been washed from the silt banks during high-water stages and were lying on sand and gravel bars in the river or at the base of the cliffs. A few fossils were collected in place.

Many of the 363 fossil mammal specimens collected are fragmentary, but more than 90 per cent of the material could be classified by field identification. Remains of mammoth and horse are the most common. Other fossil animal types identified are: moose, caribou, superbison, musk-ox, beaver, giant beaver (*Castoroides*), and wolf.

SUGGESTIONS REGARDING ADDITIONAL SUBMARINE GEOLOGICAL WORK IN THE ARCTIC

G. D. Hanna
Arctic Research Laboratory, Barrow, Alaska

Methods used in obtaining bottom samples of rock formations in warmer waters are much less effective in the Arctic for several reasons. The basin and its estuaries are covered with ice for 9 months or more and navigation with surface craft far from shore is impossible or uneconomical. The bottom is continually supplied with debris of uncertain origin, dropped by floating ice, so that outcropping rocks are rare and hard to find by ordinary dredging methods. It is believed that much useful information can be obtained on the continental shelf and slope by extending seismograph operations. This should determine the depth of the overburden to bedrock and perhaps the depth to basement. It should certainly enable the extent of the permafrost out from shore to be determined. This work can best be done on the ice in winter and spring.

Samples taken with core barrels, clam and orange-peel buckets on a small scale, can best be obtained through the ice because accessory apparatus is not beyond the capacity of a weasel and locations can be plotted with great accuracy. Air transport may well be considered in this connection.

For work during the summer in open coastal waters an LCM landing craft is about the most useful boat. It should be equipped with an efficient winch for drag-line dredging. The work on bedrock will normally be hit and miss because of the blanket of overburden, especially in the Point Barrow area.

HYDROLOGIC STUDIES OF A SUPRAGLACIAL STREAM NEAR THE FIRN LIMIT, SOUTHWEST GREENLAND

G. William Holmes
U.S. Geological Survey, Big Delta Army Post, Alaska

Stage and discharge measurements of a stream originating near the firn limit on the west slope of the Greenland Ice-cap near the Arctic Circle were made in the summer of 1953 as a part of Project Mint Julep, sponsored by the U.S. Air Force and directed by the American Geographical Society. The stream differed from terrestrial streams in respect to source of runoff, valley shape, type of transported materials, and fluctuations in daily and seasonal flow. However, the stream and its tributaries developed an ice landscape resembling a mature topography on bedrock and created patterns like those of streams on land. Furthermore, relationships between discharge on the one hand and such factors as width, velocity, and distance downstream resemble those of terrestrial streams.

GENERAL GEOLOGY OF THE KATMAI AREA, ALASKA

A. Samuel Keller
U.S. Geological Survey, Menlo Park, Calif.

The Katmai area comprises 5000 square miles of the Alaskan Peninsula. The area is one in which volcanoes have been recently active. Sedimentary rocks of Jurassic, Cretaceous, and Eocene age, and Jurassic and Tertiary intrusive rocks are present. Tertiary and Quaternary volcanic rocks locally overlie the Jurassic and Cretaceous sequence.

The Upper Jurassic Naknek formation comprises a basal marine, arkosic conglomerate, overlain by 6000–9000 feet of fossiliferous arkose, siltstone, and shale. An Upper Cretaceous sequence 4700± feet thick conformably overlies the Upper Jurassic series. The essentially nonmarine Kenai formation is at least 830 feet thick and interfingers with layered Eocene volcanic rocks.

The regional dip of the sedimentary series is southeast. The largest flexure is the Kamishak anticline, the crestal area of which is intruded. A reverse fault transects the area from Kamishak Bay to Contact Creek.

The Naknek formation was mainly derived from Lower and Middle Jurassic intrusive rocks and represents shelf deposits. The area was at base level during most of Cretaceous time. The seas transgressed during Late Cretaceous time but then generally regressed, and the area emerged during early Tertiary time. Only one major period of deformation occurred, probably after Eocene and before Quaternary time.

Although the Jurassic-Cretaceous rocks may serve as both a source and a reservoir for petroleum, and structural and stratigraphic traps may exist locally, the widespread intense igneous activity and the general lack of evidence for promising structures limits the likelihood of development of the area as a petroleum province.

RECONNAISSANCE OBSERVATIONS ON THE GEOLOGY OF THE TRINITY ISLANDS, ALASKA

C. E. Kirshner
Standard Oil Co. of California, Seattle, Wash.

The Trinity Islands, Tugidak on the west and Sitkinak on the east, form the southwesterly extent of the Kodiak Islands group. Each island is approximately 5 miles wide by 20 miles long. The surface of Tugidak Island is a series of low wave-cut terraces maximum elevation 200 feet. Sitkinak Island comprises a group of hills on the east and west, maximum elevation 1640 feet, separated by a valley enclosing Sitkinak tidal lagoon.

The bedrock of east Sitkinak Island is Cretaceous (?) marine epineritic bedded graywacke and siltstone complexly folded and faulted. West Sitkinak Island is Cretaceous (?) marine infraneritic thin-bedded siltstone and fine graywacke isoclinally folded and faulted. The thickness of these units is unknown; structural trends are northwest.

Sitkinak lagoon and valley lie in a northwest-trending graben in which about 4000 feet of Eocene (?) transitional-facies conglomerate, sand, silt, and coal crop out.

The bedrock of Tugidak Island consists of Plio-Pleistocene soft mudstone and thick-bedded gray sands, which strike N. 45°E. and dip 5°NW.

The Cretaceous sediments were deposited in a northwest-trending mobile, extra-continental, open marginal geosyncline and were probably derived from a linear orogenic land mass to the east. Late Cretaceous to early Tertiary diastrophism brought to a close the Cretaceous sedimentation cycle. The Tertiary sediments were deposited in a similar less well-developed geosyncline but had a westerly source. Intermittent orgenic uplift near the close of this cycle caused non-deposition or erosion of mid-Tertiary sediments. Late Tertiary diastrophism that closed the Tertiary cycle of sedimentation has continued to Recent time and includes differential orogenic movements and uplift, in part along major northeast-trending faults.

BUDGET STUDY OF THE LEMON CREEK GLACIER, ALASKA

Edward R. LaChapelle
American Geographical Society, New York, N.Y.

The Lemon Creek Glacier is a small valley glacier located at the southwestern edge of the Juneau ice field. An accumulation survey and records of snow and ice ablation were obtained during the summer of 1954. Methods of ice-ablation measurement and accumulation sampling were used which contributed to increased accuracy of the budget determination. Emphasis was placed on evaluation of the net water surplus throughout the ablation season. In 1954 the accumulation was considerably greater than in 1953, and this difference is attributed to high ablation caused by warm summer storms in 1953. Occurrence of these storms is thought important in determining glacial behaviour. Topographic configuration also affects the budget by leading to rapidly accelerating ice wastage as the ablation season progresses. The Lemon Creek Glacier has been retreating, with periodic pauses, since about 1750, and now appears to be entering a period of little or no retreat.

RECONNAISSANCE FOR URANIUM AND THORIUM IN ALASKA

John J. Matzko
U.S. Geological Survey, Menlo Park, Calif.

The Geological Survey has made investigations on behalf of the Division of Raw Materials, U.S. Atomic Energy Commission.

On the Seward Peninsula, metazeunerite occurs disseminated in an altered granitic lens, and metatorbernite has been traced in float material associated with a basic dike. Gummite and uranothorianite associated with pyrite have been found in the eastern edge of the Seward Peninsula. Metazeurnerite

on the dump of a copper prospect, uranothorianite and uranothorite in placers, and allanite in a gold-bearing limestone-monzonite contact zone occur in the Lower Yukon Kuskokwim Highlands region. In southeastern Alaska a highly radioactive mineral tentatively identified as pitchblende occurs associated with molybdenite and other sulphides. Also in southeastern Alaska, thorite, monazite, parisite, and bastnaesite occur in fluocarbonate hydrothermal veins. Although the presence of the carnotite-type minerals has not been confirmed in the Territory, prospectors have reported the occurrence in southern Alaska of metatyuyamunite in limestone and sandstone. In 1918, carnotite was reported in a sample believed to be from the vicinity of Healy on the Alaska Railroad. The source of tyuyamunite-bearing coal float in southeastern Alaska has not been found. Uraniferous black shale and phosphorite of Mississippian age have been found in east-central and northern Alaska.

Placer concentrates collected from widely separated parts of the Territory contain radioactive minerals such as monazite, niobatestantalates, uranothorianite, uranothorite, and zircon. Whether any Alaskan placers contain radioactive minerals in sufficient tonnage to be of economic value has yet to be determined.

PHOSPHATE ROCK FROM THE BROOKS RANGE, NORTHERN ALASKA: A PRELIMINARY MINERALOGIC REPORT

John J. Matzko
U.S. Geological Survey, Menlo Park, Calif.

Phosphorite occurs in the Mississippian Lisburne group in northern Alaska on the north flank of the Brooks Range. Preliminary studies on about 100 samples collected by U.S. Geological Survey geologists from the phosphatic zone of the Lisburne indicate that it is very similar in lithology and in phosphorus, uranium, and vanadium content to the Phosphoria formation of Idaho, Wyoming, Utah, and Montana. The phosphatic zone is composed of phosphorite, phosphatic limestone, and phosphatic mudstone. The phosphorite generally contains from 20 to 30 per cent P_2O_5, but an analysis of two selected beds shows as much as 34.0 per cent P_2O_5, 0.49 per cent V_2O_5, and 0.024 per cent U.

The Phosphorites are generally highly stained by carbonaceous matter to a dark brown or black. Phosphatic pellets range from 0.1 to 2 mm, but larger pellets up to about 5 times this size occur, forming a pavement on bedding-plane surfaces. The phosphatic pellets occur typically as massive pellets without any apparent growth rings, and less commonly as oölites showing concentric growth rings as outlined by alternating hues of brown carbonaceous matter.

Minerals occurring in the phosphate rock in varying proportions, identified by petrographic and x-ray data, are carbonate-fluorapatite, calcite, dolomite, quartz, feldspar, and fluorite. Phosphatized fish remains have also been identified. The apatite is generally cryptocrystalline, some is colloform, and it is commonly heavily stained by organic matter.

PHYSIOGRAPHY OF THE MACKENZIE DELTA REGION AND ITS RELATION TO RELOCATION OF AKLAVIK, N.W.T.

C. L. Merrill
Department of Northern Affairs and National Resources, Ottawa, Ontario, Canada

The estuarine Mackenzie Delta, 120 by 40 miles, comprises approximately 4000 square miles of small lakes and meandering channels in a network of narrow, wooded silt banks, between high ground on the East and West Delta flanks.

Mackenzie mountains parallel the Delta, rising to 3000 feet a few miles to the west. Between the river and mountains, coalescent alluvial fans extend from the southern to mid-delta, with a bedrock-controlled bench partly overlain by glacial deposits continuing to the north.

East of the delta, from south to north, a low plain on thinly mantled bedrock borders the East Channel for 30 miles. Hills of paleozoic rock, fluted by glaciation, rise to about 200 feet for the next 20 miles. A glacial moraine rising to about 200 feet extends for 15 miles to lie against the Caribou Hills, a stratified formation rising to a plateau surface at about 500 feet and bordering the channel

for 25 miles before giving way to unconsolidated deposits. These deposits, becoming more sandy toward the coast, include the northeast delta flank, Richards Island, and smaller offshore islands and appear to be of glacial and former river-delta origin.

Lack of space for expansion and unstable soil conditions required that a new townsite be selected for the growing Arctic settlement of Aklavik, N.W.T. A location on the East Channel, 33 miles east of Aklavik, proved to be most suitable in terms of the social, economic, and physical factors considered.

GEOCHEMICAL EXPLORATION FOR TUNGSTEN A SIMPLIFIED FIELD TECHNIQUE

Nalin R. Mukherjee
University of Alaska, College, Alaska

Alaska is a vast territory of unexplored regions, thinly populated, presenting peculiar problems in terms of available transportation and other facilities to persons interested in prospecting. Any quick reconnaissance method of prospecting could facilitate the exploration of new mineral bodies. Therefore, the field technique of the existing prospecting method has been simplified, and the cost of the analysis minimized.

Some simplifications have been achieved in all the methods studied so far. This paper deals with the simplification of the geochemical prospecting method for tungsten in soil and rocks. The fusion method for tungsten has been unified with that for other heavy metals to permit use of one kind of flux in the field. Moreover, the same test tubes can be used repeatedly. The different pipettes and burettes have been replaced by droppers and squirt bottles. Except the acids and extractant solutions, reagents used are solids in capsules or directly from the marketed bottles instead of solutions as used in the existing method. The volume of the extractant solution has been increased for better visual observation. Interference by the copper ion is minimized. In spite of these simplifications, the accuracy of the method of analysis has been maintained.

PRELIMINARY REPORT ON ENGINEERING PERMAFROST STUDIES IN THE GLENALLEN AREA, ALASKA*

Donald R. Nichols and John. R. Watson, Jr.
U. S. Geological Survey; Alaska Road Commission, Glenallen, Alaska

A program of thermal and soil-property studies of building and road foundations, sponsored jointly by the Alaska Road Commission and U. S. Geological Survey, was initiated during the summer of 1954.

The studies are based on data obtained from past construction, geologic investigations, laboratory analyses, and thermistor cables. Three sections of roadway at different stages of settlement and paving within a 1-mile radius of the junction of the Glenn and Richardson highways and similar in soil, drainage, and terrain features, are being investigated. Three additional sites will be located where foundation and drainage conditions are different.

Many buildings in the area have suffered structurally because of construction on permafrost without complete data on thermal regimen, moisture content, and subsurface materials. Degree of subsidence, corrective measures taken, and results have been noted for several buildings, which, along with thermal-regimen data, will aid in the determination of proper design, construction, and maintenance methods.

Preliminary results show the study areas to be underlain predominantly by silts, with a moderate to high ice content (20–50 per cent). Permafrost with comparatively low temperatures and extending from within a foot of the surface to depths of about 250 feet is encountered locally. Elsewhere in the central Copper River basin, geologic investigation has located pure-ice lenses, masses, and wedges several feet thick and constituting more than 20 per cent of a 200-foot vertical section. Under conditions such as these, the authors believe that passive-type construction methods are best suited for road and building structures.

* Publication authorized by the Director, U. S. Geological Survey.

GRAVITY STUDIES OF JARVIS GLACIER, ALASKA RANGE

Ned A. Ostenso
U. S. Army, Big Delta Army Post, Alaska

Jarvis Glacier, located at the head of Jarvis Creek and about 5 miles east of Rapids Roadhouse, is well suited for glaciological study owing to its simple outline, small size, and relatively smooth surface. This glacier is about 6 miles long and one-half mile wide, and lies in a north-facing valley between 4000 and 6000 feet above sea level. In conjunction with other glaciological studies, 76 gravity observations were made along five cross sections and along the center line of the glacier. Although this study is preliminary in nature it reveals the thickness and basal profile of the glacier.

The maximum ice thickness is 540 feet and occurs in the center of the cirque. The average ice thickness about 4 miles from the terminus is 350 feet. Computations were based on a density ratio of 3 to 1 between the rock and the ice. Vertical and horizontal control was obtained by plane-table surveying.

PHOSPHATE DEPOSITS IN NORTHERN ALASKA

William W. Patton, Jr.
U. S. Geological Survey, Menlo Park, Calif.

Deposits of phosphatic rock were found recently on the artic slope of Alaska by field parties of the U. S. Geological Survey. The deposits occur along the northern margin of the central Brooks Range in a belt of highly deformed strata of late Paleozoic and Mesozoic age. The phosphatic rock is confined principally to a zone, nearly 40 feet thick, in the upper part of the Lisburne group of Mississippian age. Samples of phosphatic rock were collected at seven separate localities. However, the phosphatic zone is well exposed at only two of these localities: the upper Kiruktagiak River and Tiglukpuk Creek. On the Kiruktagiak River the zone is 38 feet thick and averages 12 per cent P_2O_5. The upper 19 feet averages 19 per cent P_2O_5 with one 27-inch section of 27 per cent P_2O_5, 16 feet below the top. On Tiglukpuk Creek the phosphatic zone is 36 feet thick and averages 8 per cent P_2O_5. There is one 43-inch section 16 feet below the top that averages 21 per cent P_2O_5 and six beds, 1–5.5 inches thick, of 30 per cent P_2O_5 scattered through the upper 20 feet.

In view of the marked changes in facies in the Lisburne group and the complex structural conditions that prevail along the north front of the Brooks Range, much work remains to be done before the phosphate deposits can be properly evaluated.

PRELIMINARY REPORT ON THE STRATIGRAPHY AND STRUCTURE OF CRETACEOUS ROCKS ON THE SHAKTOLIK AND LOWER YUKON RIVERS

William W. Patton, Jr., and Robert S. Bickel
U. S. Geological Survey, Menlo Park, Calif.

Stratigraphic and structural studies of the Koyukuk Cretaceous basin in west-central Alaska were begun in 1954 by the U. S. Geological Survey. The preliminary investigations on the Shaktolik and lower Yukon rivers indicate the presence of two different sequences of Cretaceous rocks. Near the margin of the basin, marine graywacke conglomerate and sandstone grade upward into nonmarine sandstone, shale, and conglomerate. In the central part of the basin, offshore marine sandstone and shale grade upward into littoral marine sandstone, which in turn grades upward into nonmarine coal-bearing beds. The coarser clastic rocks near the margin are believed to grade laterally into the finer clastic rocks in the central part of the basin, but precise correlation is not yet possible.

On both the Shaktolik and Yukon rivers, the Cretaceous rocks are intricately faulted and folded so that nowhere can their total thickness be computed. A minimum thickness of 2500 feet was measured on the Yukon River between Koyukuk and Nulato.

The offshore and littoral marine sandstone in the central part of the basin has an abundant molluscan fauna including *Inoceramus cadottensis* and *Gastroplites* sp., of late Early Cretaceous age. Plant remains from the overlying coal-bearing beds are thought to be of Late Cretaceous age.

BASALT NEAR FAIRBANKS, ALASKA

Troy L. Péwé
U. S. Geological Survey, College, Alaska

Five small basalt outcrops occur 8 miles east of Fairbanks, Alaska. Field relations between the isolated outcrops are obscure, but individual structures and petrography indicate the possibility of two different deposits. The basalt overlies the Birch Creek schist of Precambrian age.

Columnar olivine basalt with intersertal texture forms steep cliffs on Brown's Hill. Olivine occurs as large and small crystals, many of which are euhedral. Laths of labradorite compose much of the rock, and large augite plates partly enclose many of them in a micro-ophitic fashion. Interstices between laths are filled with tachylite or chlorophaeite. The Chena River rock is similar except that micro-ophitic texture is not as well developed.

Basalt on Birch, Sage, and Lakloey hills exhibits fair to poorly developed pillows or bombs in the basalt matrix. It has intersertal texture, and the augite does not enclose laths of plagioclase as in the basalt of Brown's Hill. Olivine is not abundant; crystals are small and almost completely altered to iddingsite. Secondary iron-stained hexagonal carbonate crystals and glass fill the interstices between the laths. This basalt contains more tachylite and smaller labradorite laths than does the basalt on Brown's Hill and on the Chena River.

The fragmentary distribution of the lava suggests pre-Pleistocene or early Pleistocene age. The glass is unaltered, and the basalt has not been modified by metamorphism; therefore, the rocks probably are no older than Tertiary. The pillow or bomb structure perhaps indicates subaqueous extrusion and autobrecciation or ejecta accumulation near the cone.

ARCTIC RESEARCH PROGRAM OF THE OFFICE OF NAVAL RESEARCH

Louis O. Quam
Office of Naval Research, Washington, D. C.

The Office of Naval Research supports a program of research on Arctic environment and its effect on life and human activities. The greater part of the program is carried out at the Arctic Research Laboratory at Point Barrow, Alaska; but field studies are also conducted in other parts of the Arctic and Subarctic of North America and Europe.

The Arctic Research Laboratory has been in operation since 1948. It provides modern well-equipped laboratory facilities and instruments for conducting physiological, ecological, and geophysical studies. It also serves as a base of operation for field investigations and can provide small craft for limited oceanographic observations. Although the Navy and Air Force have conducted many applied-research tasks at ARL, some of which are classified, by far the greater part of the research program is conducted by civilian research institutions and universities and deals with fundamental scientific problems.

The Arctic Research Laboratory is administered by the University of Alaska and the Arctic Institute of North America assists the Office of Naval Research in developing and co-ordinating the research program. To date, 30 universities, 20 government agencies, and 4 research institutions have participated in the basic research program; and a total of 218 scientists and technicians have conducted or assisted in research tasks.

The program may include any field of science contributing to an understanding of Arctic environment or presenting problems which require investigation in an Arctic location.

COALS OF THE CORWIN FORMATION, NORTHWESTERN ALASKA

Edward G. Sable and Robert M. Chapman
U. S. Geological Survey, Washington, D. C.; College, Alaska

Coal beds of the Corwin formation (Cretaceous) are present in the Corwin-Thetis area, Alaska, on the north side of the Cape Lisburne peninsula, and in the Kukpowruk-Utukok area from Cape Beaufort northeastward beyond the Utukok River.

The Corwin-Thetis area includes about 100 square miles and contains 17 known beds 2½–9 feet thick which aggregate 74 feet. The sequences dip 30°–45° S., and are cut by probable thrust faults. Minimum inferred reserves to 60 feet in depth are estimated at 12 million tons.

The Kukpowruk-Utukok area includes more than 1500 square miles and contains several belts of coal-bearing rocks in broad synclines and narrow, tightly folded anticlinal zones. Dips range from 0° to 60°. Forty-six known coal beds, 2½–13 feet thick and aggregating more than 200 feet, are exposed along the major rivers of the area. Many of the beds are near the coast. A coal-bearing section more than 4000 feet thick is known in the subsurface near the Kaolak River.

The coal ranges in rank from sub-bituminous to medium-volatile bituminous. Twenty-eight samples from the Kukpowruk-Utukok area averaged (moisture-free basis) 13,128 Btu (maximum 14,180, minimum 11,200), volatile matter 38.0 per cent, fixed carbon 57.6 per cent, ash 6.4 per cent, and sulfur 0.33 per cent. The Corwin-Thetis coals are of similar character, but data are incomplete.

Mining operations on or near the coast may be economically feasible. The simple structure, accessible surface exposures, and large reserves of good quality are encouraging features. Deterrent factors include remoteness of the area, frozen-ground condition, short ice-free shipping season, and absence of natural harbors.

EFFECT OF VOLCANIC ASH FROM MT. SPURR ON THE CHEMICAL CHARACTER OF SURFACE WATERS NEAR ANCHORAGE, ALASKA

G. W. Whetstone
U. S. Geological Survey, Palmer, Alaska

The abnormal increase in the sulfate content of the surface waters in the vicinity of Anchorage, Alaska, during and shortly after the July 9, 1953 eruption of Mt. Spurr came from volcanic ash that fell directly into the water, or that fell on the banks and near-by ground and vegetation and was redistributed by wind. The increase in the sulfate content of the surface water after the ashfall has been related to periods of rainfall that occurred on July 18, August 1, 2, 7–11, and from August 22 to the end of the month. During the first rainfall, ash remaining on the ground and on the vegetation very close to the stream was probably washed into the stream by surface runoff; where surface runoff is important ash may have been brought from greater distances.

The low turbidity values after July 9 of Ship Creek water and the solubility of the adsorbed sulfate material on the ash grains strongly suggest that during periods of rainfall mineral matter was transported to the stream chiefly in solution; this may have been accomplished by surface runoff or by underground movement of water which had entered the soil at some distance from the stream, or both. Both processes were probably active, but the data available are insufficient to evaluate their relative importance.

PRELIMINARY GEOLOGIC EVALUATION OF THE CHENA AREA, ALASKA

John R. Williams
U. S. Geological Survey, Washington, D. C.

The Chena area includes 127 square miles of valley bottom and adjacent upland within 2 miles of the Chena and Little Chena rivers between 11 and 31 miles east of Fairbanks. This preliminary evaluation based on geologic studies emphasizes location of areas which, upon clearing for agriculture, may be subject to subsidence caused by thaw of ground-ice masses in permafrost.

Forty-two per cent of the land, located in tributary creek valleys and on alluvial fans and lower slopes, is underlain by thick deposits of frozen silt and organic silt containing minor beds and lenses of peat, sand, and gravel. Although no exposures of ice were observed, large polygonal ice wedges and scattered ice masses in these deposits are strongly suggested by the presence of thaw lakes, polygonal ground, and other microrelief features. Similar features occur in comparable geologic environments in the Fairbanks agricultural area, where subsidence and pitting are due to thaw of ground-ice, and in the Fairbanks placer-mining district, where large ice masses are exposed.

The remaining 58 per cent, free of large ground-ice masses, consists of the flood plains of the Chena and Little Chena rivers (33 per cent), poorly drained alluvial terraces (10 per cent), Chena sand terrace (4½ per cent), silt-mantled hills (10 per cent), and bedrock bluffs (½ per cent). Within these units, gullying on slopes, lack of dependable ground water on the upland, poor soil drainage on low terraces, and periodic floods on the flood plain must be considered in developing the area for agricultural or commercial use.

ABSTRACTS OF PAPERS SUBMITTED FOR MEETING IN ATLANTA, GEORGIA, DECEMBER 27–29, 1955 (SECTION E, AAAS)

SEA-ICE ASPECTS OF MODERN ARCTIC SUPPLY OPERATIONS

Charles C. Bates
U. S. Navy Hydrographic Office, Washington, D. C.

To meet the increasing need for better short- and long-term planning for Arctic bases, the U. S. Navy has a rapidly developing reconnaissance and forecasting program for sea ice. This program encompasses the entire American Arctic and is carried on with the co-operation of the United States Air Force; the Snow, Ice, and Permafrost Research Establishment of the U. S. Corps of Engineers; theatre commands; and several Canadian activities. In 1955, the work involved more than 500,000 miles of aerial ice reconnaissance and the preparation of hundreds of ice forecasts ranging in length from 2 to 120 days. The present ice reporting and forecasting system experienced a stiff test off the northern coast of Alaska during 1955 when one of the worst ice years on record was experienced at a time when the shipping effort was at a maximum.

MILITARY GEOLOGY REPORTS

Lawrence D. Bonham
U. S. Geological Survey, Washington, D. C.

The writing of reports in the field of military geology differs in several fundamental ways from writing papers for scientific publications. Location and extent of areas for which reports are written are determined by the needs of the military rather than by the interests of the geologist. Although the geology of some of these areas may be very poorly known, one requirement of military geology reports is that an interpretation be made of all parts of the area under consideration. The frequent need for interpretations based on the most meager and indirect evidence, within a definite and often short period of time, calls for the best scientific talent available. However tenuous the arguments, once conclusions have been reached they are presented as positive statements about such matters as the kind of rock to be found in an area and the effects various properties of the rock would have on military operations. Evidence and lines of reasoning on which the conclusions are based, including theories of origin and of geologic history, have no place in the final report.

Despite the technical nature of the subject matter, the report must be written for the nongeologist. This gives rise to numerous problems in presenting information as concretely as possible without distorting rather precise geological terminology and concepts.

POTASSIUM-ARGON AGES OF METAMORPHIC AND IGNEOUS ROCKS FROM THE SOUTHERN APPALACHIANS

Donald R. Carr and J. Laurence Kulp
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

Approximate minimum ages have been determined for the Cranberry gneiss, Carolina gneiss, Beech granite, and Henderson gneiss by measuring A^{40}/K^{40} ratios on samples of the whole rock. Potassium-argon age measurements have also been made on feldspar and mica minerals taken from a number of pegmatites of the Spruce Pine district. The ages obtained show the metamorphic complex to be Precambrian. The initial sedimentation in the Southern Appalachians probably goes back to 1 billion years ago. The pegmatite ages agree fairly well with the 330 m.y. value determined by uranium-lead ages and represent the last significant metamorphic event. Possible sources of error and the general reliability of the potassium-argon method are discussed.

EVALUATION OF NATURAL CONDITIONS FOR THE CONSTRUCTION OF UNDERGROUND INSTALLATIONS

Edward C. T. Chao
U. S. Geological Survey, Washington, D. C.

Studies of suitability for construction of underground installations can be made for any selected area of the world using available geologic literature, maps, and photographs. Such studies are necessarily generalized and seem particularly suited for planning purposes prior to reconnaissance or detailed field surveys. Geologic, topographic, and hydrologic factors are used to evaluate the natural conditions for the suitability of constructing tunnel-type and bunker-type underground installations. The type of information and engineering data needed for construction planning or site selection is discussed. The usefulness and value of such a study depends largely on (1) the abundance and accuracy of the geologic information; (2) the ability of the geologist to correlate geologic data with engineering data; and (3) the presentation of technical data in a form directly usable and understood by the planners. Problems of interpretation are included to illustrate the need for basic research in correlating geologic information with engineering data.

APPLICATIONS OF HYDROLOGY IN MILITARY OPERATIONS

William B. Craig
Washington District, Corps of Engineers, 1st & Douglas Sts., N.W., Washington, D. C.

Department of the Army, SR 115-15-5 dated 20 December 1949, assigned the Corps of Engineers the responsibility for the collection, analysis, and dissemination of the hydrological data required by the armed forces and the authorization to carry out the necessary research and development thereto. Those functions relating to the collection of special meteorological information were given to the Air Forces.

"Artificial Flooding," a most important consideration in an intelligence study, is defined as the increase in flooding over the existing natural flow conditions of a stream or over an area. The techniques of creating artificial floods may be classified into three general categories:

(1) *Increasing streamflow*, by breaching a dam or releasing a flood wave by outlet-gate regulation
(2) *Retarding the streamflow to raise the water surface*, by temporary dam construction
(3) *Creating drainage obstacles*, by preventing the drainage of a normally drained area; or flooding a protected area by breaching the levees or opening the tide gates.

An example of creating an artificial flood by increasing the streamflow is the breaching of the Moehne and Eder dams in Western Germany. On 17 May 1943 the RAF successfully bombed the dams and flooded the Eder, Fulda, Weser, and Ruhr valleys. More than 1200 lives were lost, and many bridges, power plants, and navigation locks were destroyed.

Two examples of artificial flooding by outlet-gate regulation are given by the cyclical flood waves released from the Isoletta Dam in the Rapido-Garigliano River sectors of Italy during January–February 1944 and the flood releases from the Hwachon Dam on the Pukhan River, Korea, in April 1951.

The German flooding of the Ay River in Normandy during July 1944, and the Ill River in Alsace during the winter 1944–1945 are examples of retarding the streamflow by temporary damming to augment the defense.

Destruction by the Germans of the pump stations draining the Pontine marshes in Italy, 1944, and the British bombing of the protective dikes of Walcheren Island, Netherlands, in 1944 are examples of artificial flooding caused by the creation of two classes of drainage obstacles.

The practical application of hydrology to military operations requires the assembly and analysis of hydraulic data for all major drainage basins of the world, far in advance of actual hostilities. The data to be assembled should include the physical description of the river (river-bottom profiles and cross sections), the man-made developments (physical dimensions, shapes, and elevations of the hydraulic structures), and the hydraulic characteristics of the river and structures (discharge rating curves and flow variation).

The physical and hydraulic data are analyzed to determine the artificial flooding potentialities of the river system and submitted to the field commander as engineer studies.

Artificial flooding techniques have played an important part in past military operations, and it is important in the future that competent engineers be available to analyze and interpret the hydraulic data for the advanced planning of military operations.

MAGNETIC MAP OF DURHAM, NORTH CAROLINA, FAULT TROUGH

John Dooley, W. R. Johnson, Jr., and H. W. Straley, III
Georgia Institute of Technology, Atlanta, Ga.

Restudy of Durham, North Carolina, Triassic basin by geomagnetic investigation leads to additional interpretations:

(1) Bordering highs and lows appear to encircle the northern terminus of the structure.

(2) The possibility of cross faulting in the neighborhood of the Neuse River, on both sides of the basin, cannot be ignored.

(3) As Harrington showed, when he mapped new border faults, the structure of the trough is by no means as simple as earlier workers, including the senior writers, were led to think.

LOWER GLACIAL LAKE MISSOULA SEDIMENTS IN MONTANA

Portland P. Fox
Cleveland, Tenn.

Although the silts and fine sands in the upper portion of this former lake are well known and have been described by several authors, there has been little recognition of the type and character of the sediments at the extreme lower portion of the lake because they are largely covered by recent alluvium or are below present river level. Recent explorations along the Clark Fork River in Montana between Stevens Creek and Bull River have penetrated more than 200 feet of brown, fat, varved clay having a liquid limit of 42–63 per cent. This clay has a dry density of 83 pounds per cubic foot and a natural water content of 31–51 per cent. Locally, a small percentage of the clay is silty and sometimes interbedded with fine sand, but the larger portion of the lake sediments in this area consists of a fat clay.

RELATION OF MINOR FRACTURES TO THRUST FAULTS

Willard H. Grant
Emory University, Ga.

The faults occur in slightly metamorphosed calcareous graywacke and are composed of a series of narrow mylonitized movement zones separated by much wider zones of rock which range from systematically fractured to brecciated.

Rock failure occurred by both flowage and fracture, probably in response to variation of mineral composition. Drag folds and shear fractures suggest that deformation was homogeneous only in small areas.

The fault planes are warped surfaces that dip 20°–58°SE.

Fractures are of two kinds: joint and shear. The joints are classified according to their approximate relation to folding. The *bc* joints tend to fan around the nose of some folds. They do not cross breccia zones and are seldom filled with quartz. The *ac* joints are quite constant in strike, cut breccia zones, and many are filled with quartz. Shear fractures occur in two intersecting sets and are nearly always filled with quartz which is rarely sheared. The fillings usually have ragged edges and seldom traverse as much as 3 feet before pinching out. Plotting these fractures shows maxima which bear a nearly constant relation to striations and fault planes. The angle between the plotted maxima ranges from 102° to 106°.

The close association of shear fractures with brecciated zones suggests that in this case brecciation was preceded by shear fracturing and followed by rotation to produce brecciation.

CORRELATION OF PETROGRAPHIC ANALYSIS AND PHYSICAL TEST DATA OF CONCRETE AGGREGATES FROM THE SOUTHEASTERN UNITED STATES

William J. Heck
Corps of Engineers, South Atlantic Division

A number of concrete aggregates from the Southeastern United States, tested by The Corps of Engineers, South Atlantic Testing Laboratory, are classified into three lithologic groups: (1) granite and gneiss, (2) limestone, and (3) cherty and quartzose sand and gravel. Petrographic analysis and physical test data of each group are correlated, and various properties of the aggregates are discussed.

No one rock type can be rated above another as to its suitability as concrete aggregate; each sample must be judged by its own characteristics.

Petrographic study must supplement the ordinary acceptance tests in order to evaluate fully the concrete-making properties of rock.

ALTERNATIVE TO THE "TACONIC OVERTHRUST" HYPOTHESIS IN WESTERN MASSACHUSETTS*

Norman Herz
U. S. Geological Survey, 270 Dartmouth Street, Boston, Mass.

The association, in western Massachusetts, of Berkshire schist and Stockbridge marble, presumed to be different facies of identical age, has been cited as evidence of the great "Taconic" thrust sheet. Geologic mapping in the Cheshire quadrangle, Massachusetts, has failed to reveal deformation along the supposed sole of this overthrust—that is, between the marble and the schist. It is more probable that this contact is a major unconformity and that the sequence is in normal stratigraphic position.

The Stockbridge marble overlies Cheshire quartzite (lower Cambrian). It includes quartzitic dolomites and marbles of early and late Cambrian age, and feldspathic, banded, and dolomitic marbles of Beekmantown age. Schistose facies are common in the upper Beekmantown section. The Berkshire schist, of probable Trenton age, transgresses older formations from west to east and is apparently equivalent to rocks mapped as Hoosac in the eastern part of the quadrangle. It begins with a graphitic calcareous schist and schistose marble and ends, in places, with another schistose marble facies. The major part of the formation is a graphitic quartz-white mica-albite schist. The Greylock schist, a chloritic-white mica-chloritoid-quartz schist, overlies the Berkshire with a conformable, gradational contact and is the youngest formation in the quadrangle.

By correlation of this sequence to Vermont and New York, it appears likely that the Stockbridge-Berkshire contact is part of a widespread angular unconformity of probable early middle Ordovician age.

ARCUATE STRUCTURES: THREE TYPES DISTINGUISHED IN BOTH THE POSITIVE AND THE NEGATIVE CLASSES

B. Ashton Keith
The Institute of Sciences, Washington, D. C.

The world literature on "arcuate structures" indicates that prior to 1939 geologists generally applied that term to curved uplifts only—such as the oxbow mountain ranges in Eurasia and the crescent island chains such as the Aleutians. By use of new methods of experimentation which shaped numerous curved structures in plastic coatings laid on very slowly shrinking spherical surfaces, it was found that negative forces as well as positive can be factors in the genesis of arcuates of two general classes. It was also found that at least three subclasses or types can be produced in each of the classes. Examples of each kind were readily found in nature.

* Published with permission of the Director, U. S. Geological Survey.

In part, then, that knowledge was tested in practical use. Drilling records have indicated that at least two of these types have relationships of some economic importance, particularly in at least one of the basin segments that compose the Gulf of Mexico. In this paper each of the kinds is shown by slide, and examples in nature are mentioned.

GEOCHEMICAL ANALYSES OF VARIOUS MINERALS AND ROCKS FOR NICKEL CONTENT

Alfred T. Navarre
Georgia Institute of Technology, Atlanta, Ga.

Nickel ion is widely distributed among various rocks and minerals. It closely follows the magnesium ion in its occurrences among national substances. Nickel has the same valence and ionic potential, as well as ionic radius, and substitutes for magnesium in the space-lattice structure. This substitution for magnesium by nickel ion was found to be true in carbonates, ortho and meta-silicates, and biotite and phlogopite micas. The presence of nickel in montmorillonite, glauconite, attapulgite, and other clay minerals was substantiated.

Magnesian chloritic schists, marble, and certain magnesian limestones held a considerable nickel content.

Several phosphate-bearing minerals contain both the magnesium and nickel ion substituting for each other in the space-lattice structure with the orthophosphate radical which is similar to the orthosilicate radical SiO_4 in its valence-bonding structure.

CROSS-COUNTRY MOVEMENT MAPS: CONCEPT AND PROBLEMS

Arnold C. Orvedal and Howard M. Smith
Soil Survey, Soil Conservation Service, U. S. Department of Agriculture, Washington, D. C.

The concern of military planners with mobility led to development of the cross-country movement map. This map shows the suitability of terrain for moving military forces without resort to roads—for movement away from roads.

It has been demonstrated that teams of earth scientists can put together comprehensive and accurate terrain information. From this, they can evaluate the suitability of terrain for movement, especially by tanks, and present their evaluations in the form of maps. This work entails problems in both analyses and presentation phases.

In the analyses phase, there are problems in collecting the raw information, deducing from this the characteristics of the relevant terrain elements, evaluating the significance to movement of the multitude of combinations of these terrain elements, and assessing the significance and occurrence of weather changes.

In the presentation on maps, there are problems in meeting requirements for simplicity, clarity, and ease of comprehension, while at the same time showing not only evaluations but also terrain facts. Furthermore, these requirements create problems in generalization, regardless of the scale of the map, as the evaluative information needs to be generalized into not more than four or five major categories for maximum effectiveness.

Considerable success can be claimed in meeting these problems, although the area for potential improvement is still large.

PEDOLOGICAL AND ENGINEERING SOIL CLASSIFICATION SYSTEMS IN TERRAIN STUDIES

Arnold C. Orvedal and Anton J. Vessel
Soil Survey, Soil Conservation Service, U. S. Department of Agriculture, Washington, D. C.

The analyst who develops information about soils for inclusion in military geology terrain studies has to deal with two fields in soils. One is pedology (soil science); the other, soil engineering. The

pedologist looks upon soils and studies them as objects in nature, just as a botanist looks upon plants. The engineer, on the other hand, looks upon soil as material for construction. Until recently there has been very little effective communication between the pedologist and the soils engineer. Consequently, each has evolved his own concept of soils, his own system for classifying them, and his own vernacular for describing them. It happens that the principal military interest about soils is in engineering. At the same time, nearly all geographic information about soils is in the field of pedology. The terrain analyst, therefore, must deal with pedological systems of soil classification and other pedological data in deriving his information, and with the engineering systems in expressing his information for military users.

DISSENTING OBSERVATIONS ON THE CONVENTIONAL EVIDENCE OF SOIL CREEP

Eldon J. Parizek and James F. Woodruff
University of Georgia, Athens, Ga.

Soil creep is a principal type of slow flowage in Sharpe's (1938) widely accepted classification of mass wasting. It presumably exists on almost every soil-covered slope with a slow but continuous movement, although imperceptible except for observations of long duration. So extensive has been the acceptance of this concept that apparent displacement of any surface object is generally accounted for by soil creep, and equally valid explanations involving other agents or types of soil movements are ignored.

The trunk curvature of trees growing on slopes is invariably cited as evidence of soil creep, although closer examination reveals that such curvature may more logically be explained by phototropic responses, slump movements or obstructions to normal growth. The type of trunk curvature which would result from the coincidence of growth and continued slow movement is notably lacking in the field and among illustrative examples used in many texts. Displacement of cultural features—*i.e.*, fences, telephone poles, retaining walls—are also allegedly indicative of soil creep. In most cases this displacement might also have been initiated by man, small animals, or by inorganic factors divorced from and not necessarily promoting soil creep.

Pertinent examples and discussion of these alternate causes are presented, and it is suggested that greater caution be exercised in the interpretation of displaced surface features, for, although some may indicate soil creep, others may result from different processes.

LANDFORM ANALYSIS IN OPERATIONAL RESEARCH

Louis C. Peltier
U. S. Geological Survey, Washington, D. C.

Measurements of parts or conditions of landforms may be statistically correlated with operational costs or risks. The probability that a landform condition will arise can be converted into terms of the probability that certain risks may have to be taken. Thus, in any particular area the chances of finding sites, with characteristics within specified limits, suitable for factories, airports, arable land, or highways can be estimated. Furthermore, the expectable cost of preparing the land for construction or utilization can also be estimated.

The method of landform analysis for these purposes consists of an identification of the relevant aspects of the landforms, the selection of a system of sampling, and a statistical manipulation of the resulting data. The most commonly significant landform factors are: local relief (R), slope (S), texture (G), roughness (r), hill height (h), and valley width (w). Some of these have special definitions. Local relief is defined as the maximum difference in elevation per square mile; texture is the number of drainageways per linear mile of transect; roughness is the number of discrete hill tops and/or peaks per square mile; and valley width is the distance between ridge crests at a random orientation with respect to the axis of the valley. These factors are mutually interrelated. Expectable local relief is related to expectable slope ($\bar{S} = 0.024\bar{R} - 0.66$); slope is related to the height of hills and the width of valleys ($\text{Tan } \bar{S} = \text{Tan } 60° \; \bar{h}/\frac{1}{2}\bar{w}$); and texture is related to valley width.

If, then, slope and local relief are taken as numerical indicators of the landform characteristics and observed by sampling, these and similar correlations permit a rapid estimate of other landform parameters and the costs or risks dependent upon them.

HUMUS OF MISSISSIPPI SOUND

Richard R. Priddy
Millsaps College, Jackson, Miss. and Gulf Coast Research Laboratory, Ocean Springs, Miss.

A dark, fine-grained, "sea humus" covers or is partly suspended above some bottoms of Mississippi Sound. This material is similar to the dark, carbonaceous, highly adsorptive, richly productive humus which is an important part of the soil in humid regions.

Above the silty, more clayey bottoms the sediment is a soft, viscous to plastic, poorly bedded blanket 1–10 feet thick. Above it is flocculent water-logged material which settles to a layer inches in thickness in calm water but which is dispersed by wave action, currents, or unusual tides.

The viscous blanket and the flocc both contain clay or silt-sized grains of quartz, chert, and macerated vegetation. Chemical analyses indicate that both, but especially the flocc, are highly aluminous, ferruginous, and magnesian gels which collect the clastics and adsorb variable amounts of gases and nitrogenous and sulfur compounds. Slight increases in pH or in salinity increase flocculation and increase adsorption, but small decreases in pH or in salinity lessen the flocculation and lessen adsorption. Annelids and some small Crustacea inhabit the bedded sediment, but it has not yet been determined if organisms use the salts in this "sea humus" as organisms use the nutrient salts of humus on land.

ROUGH EVALUATION OF CONSTRUCTION PROPERTIES OF SEDIMENTARY ROCKS BY TECTONIC ANALYSIS

N. Shreders
U. S. Geological Survey, Washington, D. C.

For evaluation of construction properties of sedimentary rocks in areas where the pertinent information is lacking and the only source is small- to medium-scale geologic maps and brief discussion of geologic history, an indirect approach is used, similar to one used for evaluation of prospects for sedimentary ore deposits. The method is based on the concept that the distribution of geotectonic elements, petrology of the areas of erosion, and climate provide the basic framework for sedimentation and determine the principal characteristics of sedimentary rocks. The following information obtained from geologic maps and brief discussions of geologic history provides necessary criteria for geotectonic analysis of the area: (1) major types of deformation, their distribution and position in stratigraphic column; (2) time and types of igneous activity with rough grouping of igneous rocks; (3) names of sedimentary rocks typical for geologic systems if mentioned in text.

With the application of the concept of "Lithologic associations" typical for basic geotectonic elements, the geologist-analyst is able to determine the principal petrologic characteristics of sedimentary rocks in the analyzed area.

The application of existing civilian or military technical requirements, which are essentially the same, to the results of analysis allows the geologist to outline the areas of occurrence of sedimentary rocks with undesirable characteristics as well as the areas where occurrence of suitable rocks is most probable.

MILITARY ASPECTS OF VEGETATION

Lloyd Spetzman
U. S. Geological Survey, Washington, D. C.

Modern military forces must be prepared for action in all possible surroundings, in any part of the world. This requires advance knowledge of existing vegetation and an understanding of the influence of vegetation on military action.

Concealment from view is best afforded by trees and other tall vegetation. The degree of concealment depends on foliage, density, and periodicity. Cover from small-arms fire is possible behind large trees. However, artillery shells may be more effective when they burst in treetops. Vegetation, either growing or cut, is extremely important in camouflage.

Ground observation and small-arms fire are limited by density and spacing of vegetation, compounded with relief. Most vegetation, except for dense forests, is only a minor handicap to aerial observation.

Cross-country movement of men and vehicles is restricted by tall, dense, or thorny vegetation, or by a combination of vegetation and other terrain conditions, such as forest or cactus-covered slopes, swamps and marshes, terraced vineyards, and irrigated rice fields. Waterways may be obstructed by dense aquatic vegetation, and shore lines may be obstructed by mangrove trees. Communications and logistics are generally more difficult to maintain during an advance through dense forests or other heavy vegetation.

Conversely, movement may be improved where vegetation affords traction or stabilizes the substratum.

BEAUFORT BASIN OF SOUTH CAROLINA

H. W. Straley, III
Georgia Institute of Technology, Atlanta, Ga.

As a part of the geomagnetic map of the Atlantic Coastal Plain, southeastern South Carolina was covered in some detail. The Beaufort magnetic basin of South Carolina lies south of the Summerville Magnetic High and is bordered by somewhat higher areas to the south, east, and southeast. On the south, the basin may open into Georgia at about Springfield. Near Port Royal Sound, the bordering high declines, leaving a connection with the Atlantic. Inland, the basin extends a tongue toward the Piedmont near the Savannah and another to the north-northwest. The isopleths do not, however, resemble topographic contours.

Although the anomalies might be attributed to several causes, the writer believes they are due to differences in lithology of the basement complex, which are probably structurally controlled.

IS APPALACHIAN DEFORMATION CONFINED TO SEDIMENTARY ROCKS?

H. W. Straley, III
Georgia Institute of Technology, Atlanta, Ga.

The writer performed pressure-box experiments applying Hubbert's modifications. The investigation failed in its purpose but had by-products: thrust faults may pass downward into folds; and deformation may not involve both basement and superficial rocks. From these and other considerations, the writer questions whether Appalachian deformation is profound. Gravity and magnetic surveys were used.

Appalachian basement and sedimentary rocks have about the same relative density. Results were inconclusive because gravity profiles show slight irregularity between plateaus and Piedmont, regardless of structure.

Basement and Paleozoic formations differ widely in magnetic susceptibility. If the crystalline rocks are deformed, magnetic profiles should indicate where, and extrapolation should reveal geometrical relations.

The gravity and magnetic irregularities may be interpreted more readily in terms of limestone than basement. The writer concluded, therefore, that Appalachian deformation is shallow in accordance with a suggestion by T. C. Chamberlin. He thinks that his conclusions have distinct bearing upon a geodynamical suggestion by Gunn.

STATE OF GROUND IN TERRAIN STUDIES: CONCEPT AND PREPARATION

Dwight W. Swanson and Franklin Newhall
Soil Survey, Soil Conservation Service, U. S. Department of Agriculture, Washington, D. C.

As employed in military-geology terrain studies, state of ground describes those conditions that are related to temperature and moisture content. Five states of ground are usually recognized: dry, moist, wet, frozen, and snow-covered; the first three are defined in terms of established soil-moisture constants. The significance of these states of ground to civilian and military activities is manifold; some states may be critical for specific operations.

A synthesis of data, principally those of climate and soils augmented, where available, by meteorological observations of state of ground, is the process by which states of ground are estimated for most areas as required in terrain studies. Areal distribution of states of ground for an entire year may be shown either on one map or on a series of seasonal maps.

PREDICTION OF GROUND-WATER CONDITIONS IN ISLAND OR COASTAL AREAS

Maurice J. Terman
U. S. Geological Survey, Washington, D. C.

The hydrology of island or coastal areas is well known in only scattered places. A study of these leads to the following conclusions:

The double-convex lens of basal water is in dynamic equilibrium, and the size of the lens as predicted from the Ghyben-Herzberg principle, which is based on static conditions, is a minimal condition.

The basal lens can be considered to be composed of:

(1) the top water-table zone in which occur the capillary fringe and the tidal and seasonal fluctuations,
(2) the bottom transition zone in which occur the interpenetration of fresh- and sea-water streamers and seasonal fluctuations,
(3) the side discharge zone in which occur subaerial and submarine seepage and springs,
(4) the middle storage zone in which basal water flows from the water table to the discharge zone.

The development, dynamics, and salinity of the basal lens are affected by:

(1) climatic and botanical conditions: precipitation and evapotranspiration control the amount of water available for recharge;
(2) geologic conditions: permeability, structure, and geologic history control the amount and distribution of basal water;
(3) topographic conditions: size and shape of landforms control the magnitude of the basal lens;
(4) resultant natural conditions: the magnitude and fluctuations of the head and of the side discharge control optimum utilization of basal water;
(5) artificial-draft conditions: the type and location of wells and manner and amount of withdrawal control salt-water encroachment.

The prediction of ground-water conditions in unknown island or coastal areas is dependent on the amount and reliability of climatic, botanical, and topographic, as well as geologic, information, and the proper application of principles.

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